

# METALLURGIA

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## The Steel Take-Over

MUCH ink has flowed and much breath been expended during the last few years in discussing the merits and demerits of the proposal to nationalise the steel industry. Both sides, for and against, have had their say—in the Houses of Parliament, on the public platform and in the press, technical and otherwise—until there must be few, if any, aspects of the subject not dealt with at one time or another.

During this period, one can but admire the dignity and correctness with which the Iron and Steel Federation has acted. Never deviating from its united opposition to nationalisation, because of its conviction that it would be highly damaging both to the steel industry's efficiency and to the public interest, it consistently represented to the Government that if their aim was to ensure that the policies of the industry conformed with national needs, it could be better attained through the medium of a statutory board, exercising supervisory functions, on the lines of the Iron and Steel Board—which operated satisfactorily from 1946-1949, when the threat of nationalisation caused its dissolution. Towards such an end, the Federation was always prepared to help, but in the political uncertainty which shrouded the nationalisation project, it plainly could not be expected to see its way to suggest the names of individuals who might serve on the Corporation which was to be set up under the Iron and Steel Act. This situation was unchanged by the verdict of the General Election in February, 1950, when the Government gained a slender majority over the Opposition parties. By no stretch of the imagination could this be interpreted as an overwhelming desire for nationalisation on the part of the electorate of this country. In fact, some one and three-quarter million more votes were cast for candidates who were against the implementation of the Act than for those who were for it. In such circumstances, the Federation still felt itself unable to make any contribution towards the formation of the Corporation, and on October 2, the Minister of Supply announced the names of those who had consented to act. Shortly afterwards the vesting date was fixed at February 15, 1951, and the Federation Council took steps to consider the policy to be adopted in the interim period. It was agreed that, since the Act imposed certain duties on the Corporation, facilities for carrying out those duties should be provided by the Industry as necessary. At the same time it was necessary that those in the Industry should continue faithfully and loyally to manage their particular firms, and also to preserve, as far as possible, those arrangements which had been so successful in the past, including the responsibility of management in the separate companies, and those common services—such as the Federation, Research Association, etc.—which had been built up over so many years for the benefit of both the publicly-owned and

privately-owned companies. On being approached by the Chairman of the Corporation to assist in finding four steelmakers to join the Corporation, the Council still felt unable to do so in view of the continuation of the circumstances which had been responsible for its turning-down the earlier request of the Minister of Supply. The services of the President and three leading steelmakers were offered, in a consultative capacity, and it was emphasised that the Industry was most anxious that there should be no failure on their part to strive to serve the national needs in the future as faithfully and successfully as they had done in the past.

So much for history—what of the future. The Iron and Steel Corporation of Great Britain has now taken over virtually the whole of the industry's production of iron ore and pig iron, and a substantial proportion of its hot-rolled steel section, and it is in the national interest that all concerned should do their utmost to see that the progress of the industry is maintained—at least, as far as raw material supplies will allow. In a press conference immediately prior to the take-over, the Chairman of the Corporation, Mr. Steven Hardie, appealed to men "who had played such a great part in the industry in the past to forget politics, accept the change brought about by Act of Parliament, and come into the team and give us their help." In order to keep the industry financially sound, modern in outlook and technically efficient, the co-operation of all the experts in the industry will be needed, and it is the hope of the Corporation that the four additional members which the Minister has power to appoint will come from within the steel industry.

The nationalisation of the steel industry differs from other nationalised undertakings in that the industrial companies retain their identity, but the Corporation, in addition to its statutory obligations has all the responsibility, obligations, power and authority, as is the normal practice in a commercial and industrial undertaking operating as a holding company. The Corporation's responsibilities will include the provision of finance for the publicly-owned companies, approval of major development schemes, prices policy, appointment of directors and special executives in the companies, and general conduct of the industry. The individual responsibility for operating the companies will fall on the directors and managements and it is the wish of the Corporation that the individual character and enterprise of the Companies, including the sales organisations at home and abroad, shall be maintained and developed. The interests of the privately owned companies are to be adequately represented and protected.

So far so good, what the outcome of the general policy of the Corporation will be remains to be seen when it is translated into hard facts, but is good to note Mr. Hardie's assurance that the Corporation has no desire for that over-centralisation of the industry which has been a disturbing feature of other nationalised undertakings.

## Correspondence

### Amalgamation of Metallurgical Organisations

The Editor, METALLURGIA,  
Sir,

The very moderately worded letter of Mr. Keating in your January issue, will, no doubt, receive the attention of the Councils of the three Metallurgical Societies which he names, but it may be helpful if I, as the signatory of the Institute of Metals Appeal, make some preliminary comments on the issues raised by him.

It is only too true that membership of such Societies, particularly of more than one, is a serious matter, for younger men especially, but it should be remembered that the rates of subscription to my own Institute (and the same is true of the Iron and Steel Institute) have increased only by 33½% in the last 20 years, and, moreover, that joint membership of more than one of the three bodies now carries appreciable reductions. It cannot be said, therefore, that the problem is caused by undue increases in the rate of subscription: the cause is rather the burden of taxation and the increased cost of living.

In contrast with this small increase in the rate of subscription, the volume of our regular publications has increased in the same period by 50%, the costs of the Institute are about three times greater, and the average expenditure per member is about twice as great as 20 years ago.

Mr. Keating asks whether the amalgamation of the three Societies could produce substantial economies. Such a possibility, although it would raise a number of very real difficulties, has certainly occurred to some of us who have been concerned in these matters, and no really promising field of economy should be neglected, but the truth is that the opportunity is limited. In the first place, the Institution of Metallurgists is a qualifying body and it must pay tax on its income. The nature of the activities of the other Institutes enables them to claim tax exemption, and for this reason, whatever might be the attitude of the Institution itself, amalgamation with it would be harmful to either of the others.

The question is, therefore, whether either in their publication expenditure or in their general overheads, the other two Institutes could effect economy by amalgamation. So far as the Institute of Metals is concerned, nearly 90% of the total expenditure goes, either directly or indirectly, in publication. The opportunity for economy in the remaining general overheads is, therefore, comparatively small, particularly as the two Institutes already share the same building and the Library services. As for the publications of the two Institutes, experience has shown that, to a considerable extent, they cater for two distinct types of membership, and that there is very little overlapping in the actual material published. A combined journal would, therefore, appear to offer little chance of a reduction in staff or in the volume of the material published, and it would have two financial disadvantages:—

1. The joint Journal would have to be circulated to a large number of Members who would not be interested in either the one half or the other, thus entailing a substantial extra cost in paper and printing charges.

2. The advertisement revenue of the combined Journal would undoubtedly be less than that earned by the two separate Journals, and this is an important point.

It is considerations such as these that have led to the conclusion that some other remedy must be sought. In my own view, it is no longer possible, under present conditions, to provide scientists with the publication services and the discussion facilities that they require without the regular assistance of the industries that may ultimately benefit. I am glad to say that the generous response to our Appeal has shown that this is widely realised by Industry. Nevertheless, no real opportunity of economy will be neglected.

I remain,

Yours faithfully,

H. S. TASKER,

President, Institute of Metals.

4, Grosvenor Gardens,  
London, S.W.1.

9th February, 1951.

### International Welding Congress

An International Welding Congress is meeting in London and Oxford from July 14th–21st. The Congress will include the annual meeting of the International Institute of Welding and its various Commissions, and is being sponsored in this country by the five British member societies, namely, the Institute of Welding, the British Welding Research Association, the British Acetylene Association, the Welding Sections of the British Electrical and Allied Manufacturers' Association and the Sheet and Strip Metal Users' Technical Association. The President of the Reception Committee is Sir William Larke, K.B.E.

The Congress will open in London on Saturday, July 14th, and will be transferred on the following day to Oxford, where three colleges, Christ Church, Oriel and Somerville, will accommodate the visitors, who are expected to number between four and five hundred.

Meetings of the 14 Technical Commissions of the Institute will occupy the first two days, and in the second part of the week there will be three open sessions for the presentation and discussion of papers as follows:—The Welding of the Wrought Light Alloys, Chairman: Sir Arthur Smout; The Welding of Bridges and Allied Structures, Chairman: Professor J. F. Baker (Cambridge University); Present Trends in British Welding (Chairman not yet appointed).

A full programme of social functions is being arranged, including a concert and a dance in Oxford and a concluding banquet at the Savoy Hotel in London on Saturday, July 21st. In the following week, facilities will be provided, through the 20 Branches of the Institute of Welding, for members of the Congress to visit works in all parts of the country.

The Secretary of the Congress is the Secretary-General of the International Institute of Welding, Mr. G. Parsloe, and the office of the Organising Committee is at 2, Buckingham Palace Gardens, Buckingham Palace Road, London, S.W.1.

### Front Cover Illustration

Our front cover illustration, provided by Richard Thomas and Baldwins, Ltd., shows the pouring of alloy steel from an electric-arc furnace at Panteg.

# Magnesium Alloy Surface Treatment\*

## Importance of Chemical Buffering

By L. F. Le Brocq, B.Sc., F.R.I.C.† and H. G. Cole, B.Sc., A.R.I.C.†

*Good buffering power is an important practical requirement for chromate treatment baths for the protection of magnesium alloys. Without it, constant additions of acid are necessary to maintain working conditions. The good buffering properties of the hot half hour chromate bath (bath iii of D.T.D.911A) at pH 6 are described in detail. Good buffering of a cold chromate bath at pH 4 to 5 can be obtained by addition of chrome alum or preferably potash alum; the action of alkali on potash alum is examined in detail in this connection. Some commercial baths are well buffered over the working range, and others are not. Extensive use is made of pH curves in this work.*

### 1. Introduction

WHEN a magnesium alloy part is treated in a chromate protective bath, a small amount of metal dissolves from the surface and passes into the bath solution, causing a reduction of some of the chromate constituent of the bath solution to the chromic  $\text{Cr}^{+++}$  state. Under suitable conditions of acidity this radicle, probably in the form of chromic chromate, ( $\text{Cr}_2\text{O}_3$ ,  $\text{CrO}_3$  approx.) is deposited on the new metal surface as a major part of the protective coating.

The dissolution of metal is equivalent to an addition of an alkali, magnesia, to the bath, and causes a rise in the pH of the bath solution and a fall in its activity. A stage will eventually be reached called the upper working pH limit of the bath, at which the bath ceases to treat, and addition of acid is necessary to restore the activity. Care must be taken, however, not to over-acidify a bath, for too great an activity will result in much metal loss during treatment, and the production of loose powdery chromate films. At still greater acidities, no chromate films will be deposited at all, as the bath solution itself is then a solvent for the films. The maximum acidity permissible to form good films is called the lower working pH limit.

The ability of a bath solution to continue treatment of large areas without frequent adjustment of acidity is of considerable importance in industry and should always be considered in the development stage of a new bath. Nevertheless, some commercial baths, as will be shown later, fail markedly in this respect.

The surface area of magnesium alloy which can be treated before revivification is necessary is determined by the weight of metal dissolving per unit area during treatment, and on the gross buffering power of the bath. The latter, in turn, depends on the working range and concentration of the bath and on its chemical composition.

The amount of metal which dissolves during treatment, and which determines the weight of chromate film deposited, is of the order of 0.05–0.10 g./sq. dm. for many types of treatment. As this figure cannot be reduced, without a corresponding reduction in the thickness of the film, the working life of a bath before revivification is necessary depends essentially on the buffering power. The latter may be increased by increasing the concentration of the solution but practical considerations, such as drag-out losses, limit the use of strong solutions. It is clear, therefore, that the practical

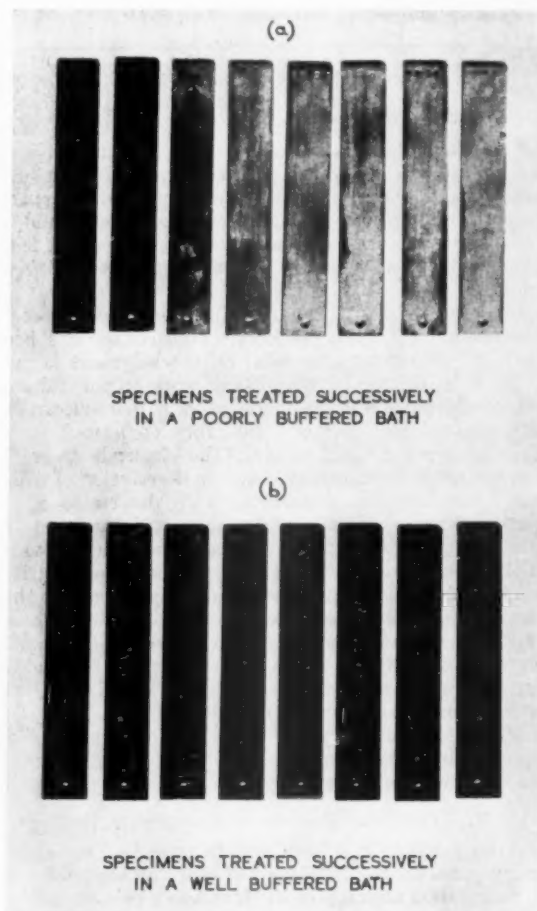


Fig. 1.—Buffering power of chromate treatment baths.

working life of a bath solution will depend largely on the true chemical buffering power over the working range.

In the testing of, or development of, new baths, lack of buffering can be demonstrated very readily. Fig. 1 shows specimens of magnesium alloy sheet (D.T.D.120A, AZM, 6% Al, 1% Zn) each of size 1.6 × 10 cm. treated one after the other in 150 ml. of freshly prepared chromate treatment solutions.

\* Translated from the original paper in *Métallurgie et Corrosion*, XXIV, No. 287–288, July–August, 1949.  
† Metallurgy Department, Royal Aircraft Establishment, Farnborough.



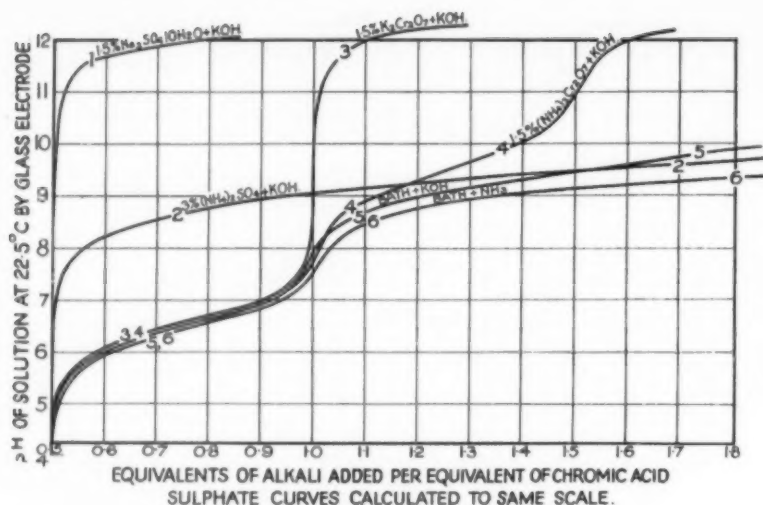


Fig. 1 (a) shows specimens treated in a poorly buffered bath; Fig. 1 (b) shows specimens treated in a well buffered bath of approximately the same total concentration. It will be seen that only two specimens could be treated satisfactorily in the first bath, whereas at least eight could be successfully treated in the well buffered solution.

In order to study the buffering power of chromate treatment baths more precisely, extensive use has been made of pH curves; grateful acknowledgment is paid to H. T. S. Britton for his pioneer work on this subject. pH measurements were made with a glass-electrode/saturated-calomel-electrode assembly connected to an electrometer valve pH meter. The electrode assembly was housed in a water thermostat, a description of which has been published elsewhere.<sup>1</sup> To determine a pH curve, stepwise additions of alkali were made to the solution under test; after each addition, the pH value of the solution was determined, samples of hot solutions being cooled for this purpose. The pH values were then plotted against alkali addition, the latter being expressed as grams per litre, for curves of immediate practical significance, or as equivalents of alkali added per equivalent of reactant in solution, for curves illustrating chemical reactions and relationships. It is hoped that in the examples given below, the great value of pH curves for investigating and illustrating chemical reactions will be made clear.

## 2. The Hot Half-hour Chromate Bath

A bath which has been widely used in England for many years for the treatment of cast and wrought parts in magnesium aluminium alloy, and to a lesser extent for magnesium manganese sheet (D.T.D.118, A.M.503), has the following composition:—

Potassium dichromate . . . 1.5% (g./100ml. solution)  
Ammonium dichromate . . . 1.5%  
Ammonium sulphate . . . 3.0%  
Ammonia S.G. 0.88 . . . 0.3–0.5 ml./100 ml.

This bath is described as bath iii in Ministry of Supply Specification D.T.D.911A. Parts to be treated are immersed in the briskly boiling bath solution for 30 minutes.

<sup>1</sup> Le Brocq, L. F., A thermostatically controlled glass electrode apparatus for pH measurements, *Chemistry and Industry*, **62**, No. 37, 330 (11.9.45).

Curve	Solution	Alkali added
1	1.5% $\text{Na}_2\text{SO}_4 \cdot 10\text{H}_2\text{O}$	KOH
2	3% $(\text{NH}_4)_2\text{SO}_4$	KOH
3	1.5% $\text{K}_2\text{Cr}_2\text{O}_7$	KOH
4	1.5% $(\text{NH}_4)_2\text{Cr}_2\text{O}_7$	KOH
5	Hot chromate bath	KOH
6	Hot chromate bath	$\text{NH}_3$

Fig. 2.—Buffering power of the hot half-hour chromate bath and its constituents.

Close control of the pH value of the bath is essential, the working range for a fresh bath being pH 5.9–6.2.

To study the buffering power of the bath, stepwise additions of magnesia, caustic potash or ammonia were made to the bath itself, or to its constituents taken one at a time; to extend the range of readings the bath was made up without the 0.3–0.5% added ammonia. Two sets of experiments were made, one in the cold in which loss of ammonia displaced from the bath was prevented, and the second in which the alkali (magnesia in this case) was added to the boiling bath and the liberated ammonia was allowed to escape freely, the level of the liquid being kept constant by addition of distilled water. The boiling was continued after each addition until the pH fell to 5.90 or below, or until further additions of magnesia caused a permanent rise in pH value however long the bath was boiled. The effect of adding magnesia in this way was to convert more and more ammonium dichromate and ammonium sulphate into the corresponding magnesium salts. The results of these experiments are shown in Figs. 2 and 3.

Fig. 2 shows the results obtained with the constituents of the bath or with the bath itself when no ammonia is allowed to escape from it. It will be seen (curve 2) that ammonium sulphate has no appreciable buffering power over the working range of the bath. Both ammonium dichromate and potassium dichromate, on the other hand (curves 3 and 4), have a very fair buffering over the range, the two salts being equal in value when judged on a molecular basis. This buffering, due to the conversion of dichromate into chromate, is clearly the basis of the buffering power of the complete bath when no ammonia loss is allowed. The second "flat" of the ammonium dichromate curve shows the conversion of ammonium chromate into potassium chromate and ammonia. It is interesting to note that this curve is of the same form as if the liberated ammonia had in fact been precipitated from solution. This is doubtless due to the fact that aqueous solutions of ammonia contain but little ionised ammonium hydroxide.

Fig. 3 shows the effect of the addition of magnesia to the bath when ammonia loss is allowed (curve 8) and again when it is not (curve 7). The effect of adding magnesia to an "exhausted" bath is also shown (curve 9). By an exhausted bath is meant one in which all the



ammonium dichromate or ammonium sulphate have been converted into the corresponding magnesium salts. To do this requires 11.47g. of magnesia (MgO) per litre of bath solution.

From curves 7 and 9 it will be observed that the effect of replacing ammonium salts by magnesium salts is to lower, somewhat, the pH range at which the hot bath is buffered. The real advantage of the presence of ammonium salts is made clear in curve 8 (addition of magnesia with ammonia loss). It will be seen from this curve that before the upper working limit of the bath is reached, (pH 6.20) some 13g. of magnesia, or corresponding amount of magnesium from work being treated is required. Where true buffering only is being relied on (curve 7) this limit is attained when only about 0.6g. of magnesia have been dissolved. When ammonia loss is allowed, therefore, the bath is, from the practical point of view, twenty-two times as efficient as when it is not. These figures may be calculated in terms of area of magnesium alloy surface treatable per litre of bath; thus as already mentioned, it has been found that about 0.1g. of metal is dissolved in the bath during the half-hour treatment of 1 sq. dm. of surface. Neglecting the presence of alloying constituents, therefore, about 0.17g. MgO enter the bath per square decimetre of treated surface. The buffering of the bath without ammonia

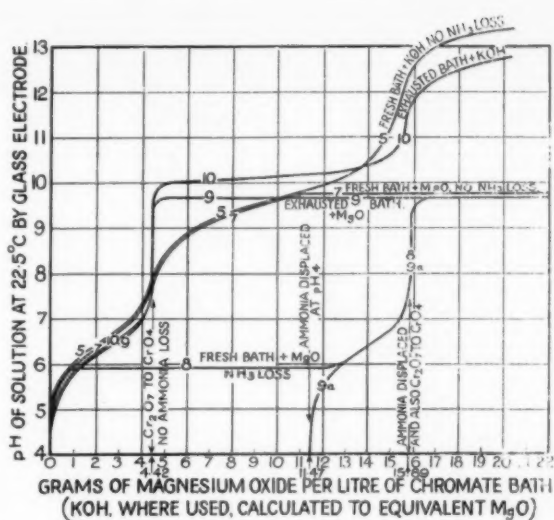
loss may therefore be expressed as  $\frac{0.60}{0.17}$  sq. dm. = 3.5 sq. dm. of surface treatable per litre of bath, or with ammonia loss as  $\frac{13.0}{0.17} = 77$  sq. dm.

It should be remembered that the adjective "exhausted" has been used with the rather restricted meaning of a bath exhausted of ammonium salts. Such a bath will, of course, continue to treat magnesium alloys almost indefinitely, but the pH value will have to be adjusted for each 3.5 sq. dm. treated per litre.

### 3. Buffer Agents for Cold Baths

The hot half-hour chromate bath described above is one of the few baths which is worked hot, and also one of the few containing only alkali metal and ammonium salts. Before proceeding with a description of individual cold treatment solutions for magnesium alloys, it is proposed to describe a systematic search undertaken by the authors for buffering agents for cold baths. The information provided by these experiments has provided a background of knowledge against which the working properties of commercial baths may be examined.

Experiments on the activity of baths containing the chromate and sulphate radicles showed that at room temperatures a pH value of approximately 3-5 was required for a treatment within reasonable time. The curves already illustrated above showed that dichromate and alkali sulphate solutions alone have no buffering power in this region, and this was readily confirmed by trial, the results being similar to those illustrated in Fig. 1 (a). Preliminary experiments showed that if the sulphate were added as potash alum, however, the solution showed a marked contrast in behaviour, and treated a large area before readjustment of acidity was necessary. It was therefore decided to determine the pH curves of a mixture of potassium dichromate with alum, or with other metal sulphates (other than alkali metal sulphates). In order that greater insight into the earlier part of the curve could be obtained (pH 4 and below), the chromate radicle was added as chromic acid



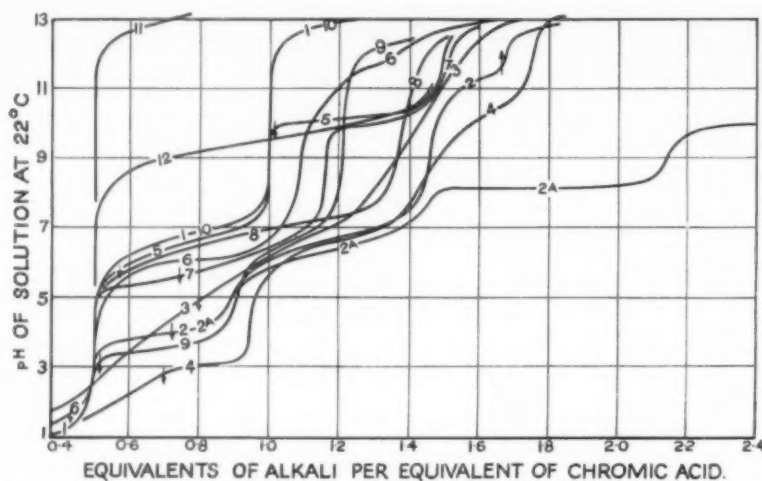
Curve	Solution	Alkali
5	Fresh bath (no ammonia loss)	KOH
7	Fresh bath (no ammonia loss)	MgO
8	Fresh bath (ammonia loss)	MgO
9	Exhausted bath	MgO
9a	Exhausted bath (Origin displaced to 11.47 g.p.l. MgO)	MgO
10	Exhausted bath	KOH

Fig. 3.—Buffering power of the hot half-hour chromate bath (addition of alkali to bath with and without  $\text{NH}_3$  loss).

three-quarters neutralised to the potassium dichromate stage.

The solutions were all normal with respect to chromic acid (50g.  $\text{CrO}_3$ /litre) and half-normal with respect to the added sulphate. The following table shows the actual concentrations in grams per litre:—

Curve No.	Name of salt added to N chromic acid (50 g.p.l. $\text{CrO}_3$ )	Chemical formula of salt	Molecular weight	Equiv. weight	Grams of salt per litre
1	No added salt				
2	Potassium alum	$\text{K}_2\text{SO}_4 \cdot \text{Al}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$	948	$\frac{948}{6} = 158$	79.0
3	Chrome alum	$\text{K}_2\text{SO}_4 \cdot \text{Cr}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$	998	$\frac{998}{6} = 166$	83.0
4	Ammonium iron alum	$(\text{NH}_4)_2\text{SO}_4 \cdot \text{Fe}_2(\text{SO}_4)_3 \cdot 24\text{H}_2\text{O}$	965	$\frac{965}{6} = 161$	80.5
5	Manganese sulphate	$\text{MnSO}_4 \cdot 4\text{H}_2\text{O}$	223	$\frac{223}{2} = 112$	56.0
6	Zinc sulphate	$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	287	$\frac{287}{2} = 144$	72.0
7	Nickel sulphate	$\text{NiSO}_4 \cdot 7\text{H}_2\text{O}$	281	$\frac{281}{2} = 141$	70.5
8	Copper sulphate	$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	249	$\frac{249}{2} = 125$	62.5



Curve	Alkali	Chromic Acid	Added Salt
1	KOH	N CrO <sub>3</sub>	None
2	KOH	N CrO <sub>3</sub>	N/2 Potash Alum
2A	Mg(OH) <sub>2</sub>	N CrO <sub>3</sub>	N/2 Potash Alum
3	KOH	N CrO <sub>3</sub>	N/2 Chrome Alum
4	KOH	N CrO <sub>3</sub>	N/2 Iron Alum
5	KOH	N CrO <sub>3</sub>	N/2 MgSO <sub>4</sub>
6	KOH	N CrO <sub>3</sub>	N/2 MnSO <sub>4</sub>
7	KOH	N CrO <sub>3</sub>	N/2 ZnSO <sub>4</sub>
8	KOH	N CrO <sub>3</sub>	N/2 NiSO <sub>4</sub>
9	KOH	N CrO <sub>3</sub>	N/2 CuSO <sub>4</sub>
10	KOH	N CrO <sub>3</sub>	N/2 K <sub>2</sub> SO <sub>4</sub>
11	KOH	None	N/2 K <sub>2</sub> SO <sub>4</sub>
12	KOH	None	N/2 (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>

Fig. 4.—Buffering power of solutions of chromic acid with added salts.

Stepwise additions of 8N caustic potash were made to each of these solutions at room temperature. After each addition the solution was stirred briskly for two minutes and the pH determined. The pH curves are shown in Fig. 4. The points at which precipitation started are indicated on the curves by downward pointing arrows. Complete re-solution of a precipitate is shown by an upward pointing arrow.

It will be seen that all the added salts gave rise to buffering at pH values below those of potassium dichromate—chromate alone, but that only chromium, aluminium, iron and copper buffered appreciably in the range pH 3–5.

Potash alum and chrome alum gave no precipitate over the first half of the buffering range but a precipitate was formed in the copper solution throughout the buffered region and in the iron solution from pH 2.5 upwards.

As this tendency to deposit a precipitate was found to interfere with the smooth formation of a chromate film, only chrome alum and potash alum were selected for further study.

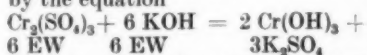
#### 4. Buffering Power of Chrome Alum ; Long Period Curves

Preliminary work on the chrome-alum potassium-dichromate curve, revealed that the shape and position of the curve determined in the cold depended markedly on the length of time of stirring between additions of alkali and pH measurement. It was finally found that

a close approximation to complete equilibrium was attained after mechanical shaking for two days in a closed bottle.

The equilibrium curve is shown in Fig. 5, together with curves for chrome alum alone in the cold (curves 1 and 2), and for chrome alum with and without potassium dichromate at 100° C. It was found that at 100° C. only 15–30 minutes stirring was required for a steady pH value.

It will be seen that the long period curve 5 is appreciably different in shape from the short period curve 4, the quick curve being a smoothed out form of the long (true) curve. In curve 2 for chrome alum alone, the precipitation range does not extend to the 1.0 equivalents mark required by the equation



It is probable that the first precipitate is of a basic sulphate which is progressively decomposed to chromium hydroxide over the range pH 5–10. Curves 3 and 6 show that a rise of temperature to 100° C. lowers the pH at which precipitation occurs.

The precipitate formed in the solution of chrome alum was grey green in colour throughout; when chromates were present, the colour varied from dark brown at low values to green at high pH values.

The initial brown precipitate is a chromic chromate and probably resembles chromate films deposited on magnesium alloys.

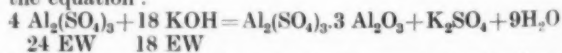
The results show that, in practice, a cold chromate bath buffered with chrome alum would become fairly quickly exhausted with use, but would recover its activity if allowed to stand for a considerable time. The bath should not be heated during its preparation and use.

#### 5. Buffering Power of Alum Solutions

The buffering curves of solutions of potassium alum, with and without N chromic acid, determined with two minutes' or two days' stirring between alkali additions, are shown in Fig. 6.

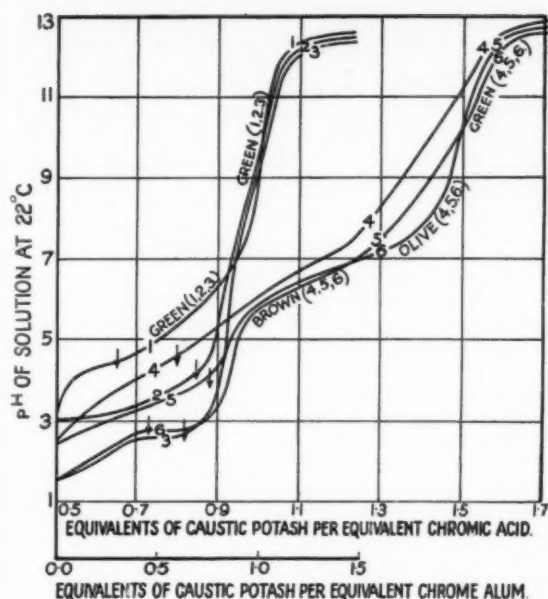
Comparison of curves 4 and 5 shows that the pH of a cold bath buffered with potassium alum is quickly re-established at a steady value after addition of alkali.

The sharp upward turn of the potash alum curves (Nos. 1 and 2), when 0.75 equivalents of alkali had been added to each equivalent of alum, suggested that the precipitate was a basic aluminium sulphate in which three-quarters of the sulphate radicle of aluminium sulphate had been converted to hydroxide, according to the equation:



It will be seen that the equation demands 3 equivalents of potash for 4 equivalents of alum, i.e. 0.75 per 1.0.

It was felt that it would be interesting to confirm this by a determination of the composition of the precipitate



Curve	Alkali	Chromic Acid	Added Salt	Conditions
1	KOH	—	N/2 Chrome Alum	22° C. 2 min.
2	KOH	—	N/2 Chrome Alum	22° C. 2 days
3	KOH	—	N/2 Chrome Alum	100° C. 4 hours
4	KOH	N CrO <sub>3</sub>	N/2 Chrome Alum	22° C. 2 min.
5	KOH	N CrO <sub>3</sub>	N/2 Chrome Alum	22° C. 2 days
6	KOH	N CrO <sub>3</sub>	N/2 Chrome Alum	100° C. 4 hours

The colours of the precipitates produced are shown on the curves, the numbers immediately following the colour descriptions are curve numbers.

Fig. 5.—Buffering power of chrome alum solutions under various conditions.

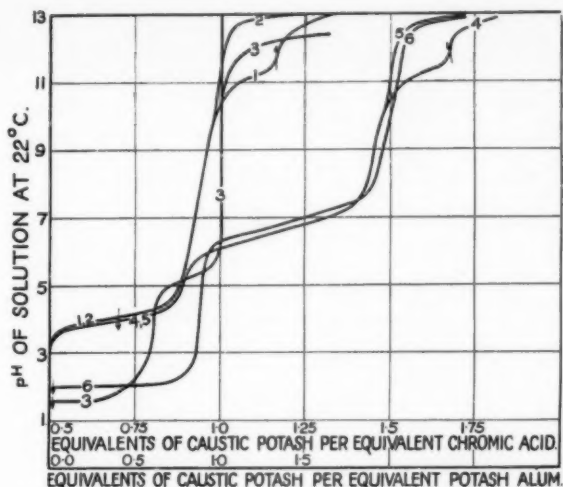
at various points along the range of precipitation. As direct analysis of the precipitate was not considered feasible, the solutions were filtered and the clear filtrate analysed for aluminium, sulphate and potassium, the composition of the precipitate being then calculated by difference.

The results are plotted in Fig. 7 which shows the amounts, in equivalents, of alumina and sulphate precipitated from one equivalent of alum dissolved in two litres of water, and the amount of potassium present in solution. The following deductions may be made from the curves:—

(a) *Potassium*.—The amount of potassium sulphate found in solution approximated closely to the total amount of the salt present, derived from the potash alum and from the added caustic potash. No appreciable amount of potassium, therefore, was present in the precipitate.

(b) *Alumina*.—Precipitation of alumina was complete when 0.8 equivalents of caustic potash had been added per equivalent of alum.

(c) *Sulphate*.—The amount of sulphate precipitated rose as the total amount of precipitate increased, reached



Curve	Alkali	Chromic Acid	Added Salt	Conditions
1	KOH	—	N/2 Potash Alum	22° C. 2 min.
2	KOH	—	N/2 Potash Alum	22° C. 2 days
3	KOH	—	N/2 Potash Alum	100° C. 4 hours
4	KOH	N CrO <sub>3</sub>	N/2 Potash Alum	22° C. 2 min.
5	KOH	N CrO <sub>3</sub>	N/2 Potash Alum	22° C. 2 days
6	KOH	N CrO <sub>3</sub>	N/2 Potash Alum	100° C. 4 hours

Fig. 6.—Buffering power of potash alum solutions under various conditions.

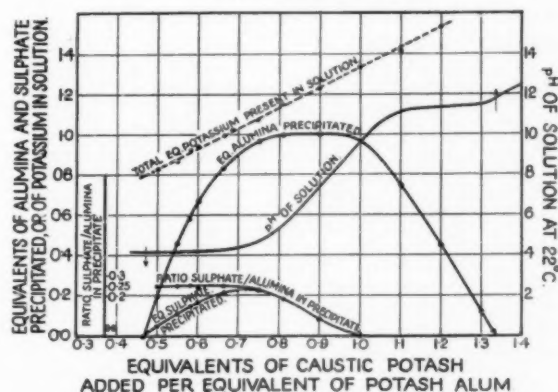


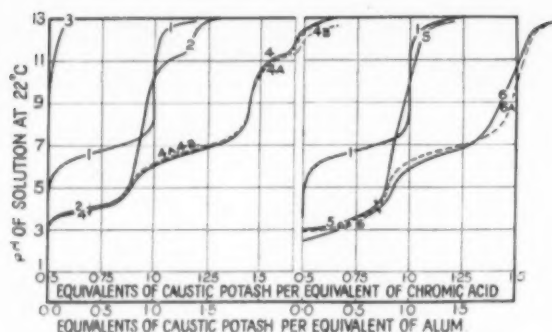
Fig. 7.—Study of reaction—potash alum and caustic potash. (Determination of composition of precipitate formed when caustic potash is added to one equivalent of alum in 2 litres of water).

a maximum at the 0.75 equivalents point, and then fell again. None remained at the 1.0 equivalents mark.

(d) *Sulphate/alumina ratio*.—This ratio showed a constant value of 0.25 from the start of precipitation (approx. 0.46 equivalents point) to the 0.75 equivalents point. The ratio indicates that the composition of the precipitate is, in fact,  $\text{Al}_2(\text{SO}_4)_3 \cdot 3\text{Al}_2\text{O}_3$ , of unknown hydration. Further addition of caustic potash decomposes this substance into hydrated  $\text{Al}_2\text{O}_3$ .

Referring again to Fig. 6, it will be seen that there is a further buffered range at the alkaline end of the curve,

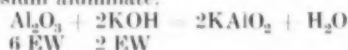




Curve	Solution	Curve	Solution
1	N CrO <sub>3</sub>	4B	Synthetic Curve, 1 + 2 + 3
2	N/2 Potash Alum	5	N/2 Chrome Alum
3	Potassium Permanganate	6	CrO <sub>3</sub> + Chrome Alum
4	CrO <sub>3</sub> + Potash Alum + Potassium Permanganate	6A	Synthetic Curve, 1 + 5
4A	Synthetic Curve, 1 + 2		

Fig. 8. Addition of pH curves.

corresponding to the re-solution of aluminium hydroxide to potassium aluminate.



a reaction which is complete when 0.33 further equivalents of caustic potash have been added to each equivalent of aluminium.

This re-solution as aluminate did not occur in the solution at 100°C., nor in the cold solution stirred for two days between each addition of alkali. In these cases, therefore, it is evident that the aluminium hydroxide had undergone a slow transformation into a different and insoluble form.

The changes taking place when caustic potash is added to N/2 potash alum solution may be summarised as follows:—

Equivalents of caustic potash to one equivalent of alum	Reaction
0.0 to 0.4	A basic sulphate is formed which remains in solution.
0.4 to 0.75	A basic sulphate is precipitated according to the equation $4 \text{Al}_2(\text{SO}_4)_3 + 18 \text{KOH} = \text{Al}_2\text{SO}_4 \cdot 3\text{Al}_2\text{O}_3 + 9 \text{K}_2\text{SO}_4 + 9 \text{H}_2\text{O}$ .
0.75 to 1.0	The basic sulphate is decomposed according to the equation $\text{Al}_2\text{SO}_4 \cdot 3\text{Al}_2\text{O}_3 + 6 \text{KOH} = 4 \text{Al}_2\text{O}_3 + 3 \text{K}_2\text{SO}_4 + 3 \text{H}_2\text{O}$ .
1.0 to 1.33	The precipitated hydrated oxide is redissolved to form potassium aluminate $\text{Al}_2\text{O}_3 + 2 \text{KOH} = 2 \text{KAlO}_2 + \text{H}_2\text{O}$ . (A reaction which does not take place if the hydrated alumina has stood in contact with the cold solution for several days).

Returning to Fig. 5, comparison of curves 4 and 6 shows that when a solution containing alum was boiled, the pH range over which the salt caused buffering was lowered, an effect already noticed on a lesser scale with chrome alum solutions. The reasons for these changes are not clear, but it was noted that the alumina precipitated from a boiling solution was dense and sandy, and

only soluble with difficulty in acids. Alumina precipitated in the cold, on the other hand, was gelatinous and easily soluble in acids.

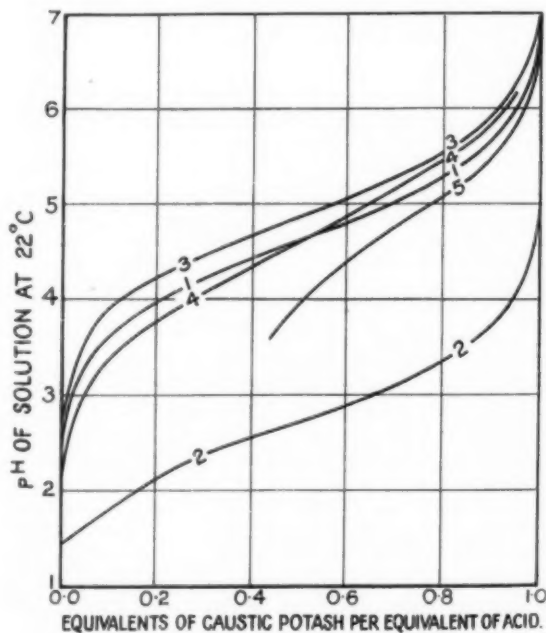
It was concluded that potassium alum was a satisfactory buffering agent for a cold chromate bath. The bath should not be heated during preparation and use. Potash alum is used as a buffer agent in the R.A.E. cold immersion chromate bath (bath ii of D.T.D. 911A), described in a later section of this paper.

## 6. Addition of pH Curves

The close similarity of the first portions of the buffer curves for potassium alum, with or without addition of chromic acid (curves 1 and 4 of Fig. 6), suggested that the course of the precipitation of very basic aluminium sulphate was unaffected by the presence of chromates. Conversely, the separation of curves 1 and 4 in Fig. 5 suggested that the presence of chromate did affect precipitation from a chromium salt, a deduction confirmed by the colour of the precipitate.

These effects are more clearly shown in Fig. 8, in which synthetic curves for the two alums and chromic acid have been constructed, by adding together the abscissae of the curves for chrome alum and potash alum respectively to the abscissae of the curve (curve 1) for the addition of caustic potash to chromic acid. The actual curves for the two mixtures are also reproduced in Fig. 8.

It will be seen from Fig. 8 that the real and synthetic



Curve	Solution
1	N Acetic Acid (CH <sub>3</sub> COOH)
2	N Chlor-acetic Acid (CH <sub>2</sub> Cl.COOH)
3	N Propionic Acid (C <sub>2</sub> H <sub>5</sub> COOH)
4	N Succinic Acid (CH <sub>2</sub> COOH) <sub>2</sub>
5	N/2 Phthalic Acid o-C <sub>6</sub> H <sub>4</sub> (COOH) <sub>2</sub> (Soluble Range)

Fig. 9.—Buffering power of organic acids.

curves for the chromic-acid/potash-alum solution (curves 3 and 3A) are closely similar, indicating that each constituent has exerted its own buffering properties, undisturbed by chemical interaction with the other constituent. With the chromic acid and chrome alum, however (curves 5 and 5A), divergence between the real and synthetic curves shows a modification of the buffering power of each constituent by interaction.

It is thought that this method of determining whether two (or more) substances interact on addition of alkali, (or acid) is of general application.

## 7. Organic Acids as Buffer Agents

Concurrently with work on inorganic salts buffering in the region pH 3-5, an investigation was made of organic acids which might be expected to buffer in the same region. Reference to published tables of dissociation constants (pKa values) indicated a number of likely compounds. The choice was, however, considerably limited by the requirements of relative cheapness, solubility in water and especially stability to potassium dichromate in the cold.

The following table shows the results of tests on a number of likely acids for stability towards potassium dichromate at room temperature:—

Stable to potassium dichromate	Not stable to potassium dichromate
Acetic acid	Oxalic acid
Chloroacetic acid	Tartaric acid
Propionic acid	Citric acid
Succinic acid	Salicylic acid
Phthalic acid (as potassium hydrogen phthalate)	Sulphanilic acid

The buffering curves of the five acids found to be stable to potassium dichromate are shown in Fig. 9. It will be seen that all five show some buffering in the range pH 3-5.

Experiments were made on the chromate-treating properties of solutions of potassium dichromate, buffered with each of the five acids in turn, with added potassium sulphate as activator salt. Solutions buffered with chloroacetic acid or acetic acid gave good treatments, but were unstable during treatment, the treatment acting as a trigger setting off the oxidation of the organic acid by the potassium dichromate.

Good treatments without reduction were obtained with the solutions containing:—

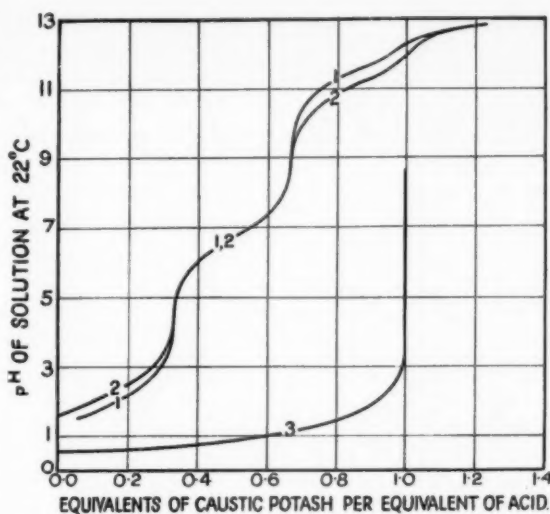
- Phthalic acid (as the potassium hydrogen salt)
- Propionic acid
- Succinic acid

Little work has yet, however, been done at R.A.E. on baths of this type, though they have been examined independently by other workers.<sup>2</sup>

## 8. Inorganic Acids as Buffer Agents

The following inorganic acids were also investigated:—  
(a) *Arsenic acid*.—Published pKa values for this acid were discordant.

Source	pKa <sub>1</sub>	pKa <sub>2</sub>	pKa <sub>3</sub>
Handbook of Chemistry and Physics, 24th Edition 1943, evidently quoting Blanc, J. Chim. Phys. 1902, 18, 28.	2.39	4.40	9.22
Lambert and Bornstein quoting Britton and Johnson, J. Chem. Soc. 1934, 1048.	2.25	6.77	11.53



Curve	Solution
1	N Phosphoric Acid (3.27% $H_3PO_4$ )
2	N Arsenic Acid (4.73% $H_3AsO_4$ )
3	N Sulphamic Acid

Fig. 10.—Buffering power of inorganic acids.

A pKa<sub>2</sub> value of 4.40 would give buffering over the required range; it was decided to determine the pH curve for the acid.

(b) *Phosphoric acid*.—Published pKa values (2, 7 and 12) indicated no buffering at pH 3-5. This acid has, however, been used in some commercial chromate baths.

(c) *Selenious acid*. Again, published pKa values (2.5 and 8) indicated no buffering at pH 3-5. A combined selenious-acid potassium-dichromate bath had been found at R.A.E., however, to give a good protective treatment.

(d) *Sulphamic acid*,  $(NH_2SO_3OH)$ .—It was thought that the basic ammonia radical might modify the strength of the acid sulphonic group and cause it to buffer at about pH 3; no pKa value for the acid could be found in the literature.

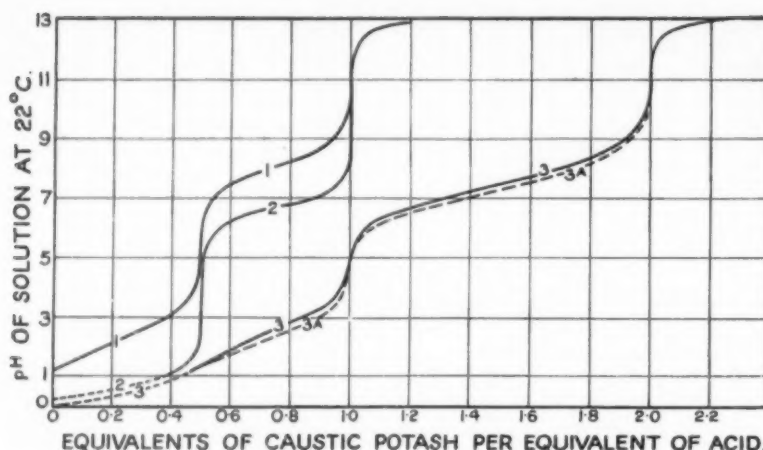
The pH curves for the addition of caustic potash to normal solutions of these acids are shown in Figs. 10 and 11. Fig. 10 shows that neither phosphoric, arsenic nor sulphamic acids buffer appreciably over the range 3-5. The pKa values for arsenic acid, taken as the pH values at half neutralisation of each stage in turn can be deduced from the curve as follows:—

$$pK_{a1} = 2.3 \quad pK_{a2} = 6.6 \quad pK_{a3} = 11.0$$

These figures confirm those of Britton, in opposition to those of Blanc.

Fig. 11 shows the curves for N selenious acid, N chromic acid and for a mixed solution normal to both acids. A synthetic curve (3A) for the mixed solution has been drawn by adding the abscissae of the two single curves 1 and 2. It will be seen that curve 3A approximates closely in shape to the real curve (3) for the mixture, indicating that no appreciable chemical reaction took place between the two constituents, a conclusion

<sup>2</sup> U.S. 558,983, Magnesium Metal Corporation and G. E. Conner.



Curve	Solution
1	N Selenious Acid (6.46% $H_2SeO_3$ )
2	N Chromic Acid (5.00% $CrO_3$ )
3	N Selenious Acid and N Chromic Acid (6.46% $H_2SeO_3$ + 5.0% $CrO_3$ )
3A	Synthetic Curve, 1 + 2

Fig. 11.—Buffering action of selenious acid.

also apparent from the absence of reduction products of chromic acid. The real curve for the mixed solution, however, is somewhat higher than the curve obtained by addition; this effect is probably due to a reduction of the degree of ionisation of each acid by the other.

It was concluded that apart from selenious acid, which will be discussed immediately below, no useful common inorganic acid buffer was available for cold chromate baths.

#### 9. Selenious Acid in Chromate Bath

It has been found that the combined solution, normal with respect to both selenious acid and chromic acid, will deposit protective films on magnesium alloys at pH values from less than 1.0–8.3, i.e. over almost the entire length of the buffering range, from the chromic acid and selenious acid stage to the potassium chromate and potassium selenite stage. As it has also been found that a solution of selenious acid alone will deposit films over the same pH range, the combined bath may be regarded rather as a modified selenious acid bath than a chromate bath containing a special buffer agent.

#### 10. Buffering Power of Some Commercial Chromate Baths

The importance of good buffering power has been made clear in the preceding paragraphs, and has been adopted as an essential in the search for new cold treatments. It is now proposed to examine the practical buffering power of some commercial baths described in the literature.

pH curves of the baths, in terms of grams of added caustic potash per litre of solution, are shown in Fig. 12. The working ranges of the baths are indicated by thickening the curves. The pH curves determined in this way allow a direct comparison to be made between the gross buffering powers of the baths as actually made up but do not, of course, indicate the true chemical buffering powers of the constituents, since a bath containing a large amount of a constituent of small intrinsic buffering power might give the same result as one containing a small amount of a constituent of high intrinsic buffering power.

(a) *R.A.E. hot half-hour chromate bath.* (B.P. 353,415, Bath iii of Ministry of Supply Specification D.T.D.911A). The buffering power of this bath has already been discussed earlier in this paper. Buffering curves for this bath are reproduced in Fig. 12 (curves 1A and 1B) for comparison.

(b) *R.A.E. cold immersion bath.* (B.P. 510,353, Bath ii of D.T.D.911A). The composition of the bath is:—  
Sodium dichromate ( $Na_2Cr_2O_7 \cdot 2H_2O$ ) .. 10%  
Potassium alum ( $K_2SO_4 \cdot Al_2(SO_4)_3 \cdot 24H_2O$ ) .. 10%  
Potassium permanganate ( $KMnO_4$ ) .. 5%

The parts to be treated are immersed in the bath for 30 minutes at 18–25°C., with stirring. Working pH range 3.0–4.2. This bath relies on the buffering power of the potash alum, which has already been fully discussed. Addition of potassium permanganate has no influence on the buffering. This salt improves the appearance of the film produced, and increases the degree of protection given to the metal when supplemented by paint.

Curve 2 shows that this bath is well buffered over the working range.

(c) *R.A.E. anodic chromate bath.* (B.P. 493,935; bath is of D.T.D.911). The composition of the bath is:—

Sodium dichromate ( $Na_2Cr_2O_7 \cdot 2H_2O$ ) .. 15%  
Potassium permanganate ( $KMnO_4$ ) .. 5%  
Caustic soda ( $NaOH$ ) .. 0.2%

Treatment in the bath is carried out at room temperature for 20 minutes at an anodic current density of 0.3–0.9 amp./sq. dm. The bath is well buffered over the working range (pH 5.5–7.5) (curve 3).

(d) *Commercial chromate bath containing transitional element sulphate.* Parts are immersed in the solution for 5–45 minutes, depending on the temperature. The pH curves for the solution, both boiling and cold (4H, 4C), are shown in Fig. 12. The cold bath is well buffered over the working range, but the hot bath is not so well buffered. Precise control of the pH value of the hot bath would probably be difficult.

(e) *Commercial bath containing alkali persulphate.\** Parts are immersed for 30 minutes in the bath at room temperature. The pH curve of the bath (curve 5) shows that the solution is unbuffered over the working range.

(f) *Commercial bath containing alkaline earth sulphate.* Parts to be treated are immersed in the bath for 30 minutes at room temperature. Curve 6 shows that the bath is unbuffered over the working range, pH 3.9–5.4. It is clear from the curve that no matter how concentrated the solution may be, no appreciable improvement in buffering power over the working range will be obtained.

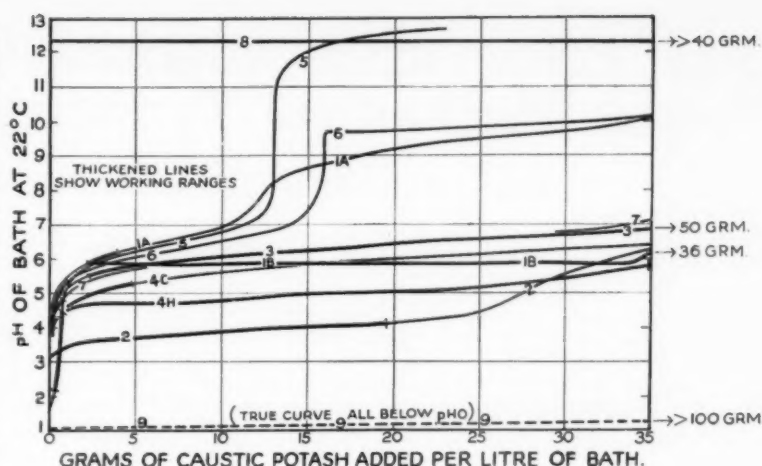
\* Private Communication from Author.



(g) *Commercial anodic bath containing phosphates.* The parts are anodised in the bath for 45 minutes at 50° C. at 0.9 amp./sq. dm. Curve 7 of Fig. 12 shows that the bath is unbuffered over the working range pH 4.0-4.8. The curve shows a long buffered range from pH 5.5-7.5 (over which the bath does not give satisfactory treatment) due to conversion of dichromate ion into chromate ion, and di-hydrogen phosphate to monohydrogen phosphate ion. It is clear that for this bath also, the buffering power over the working range cannot be appreciably increased by increasing the concentration of the bath.

(h) *Commercial strongly alkaline anodic baths.* Many alkaline anodic baths have been described in the literature, employing as constituents:—caustic soda, sodium carbonate, sodium cyanide, potassium chromate, potassium nitrate and sodium phosphate. Curve 8 of Fig. 12 shows a representative of this class, well buffered because of its strong alkalinity. In these baths the tendency will be for the pH value to fall due to absorption of carbon dioxide from the air. Magnesium cannot enter the solution if the pH value is greater than that for the precipitation of magnesium hydroxide (pH 10.7 in water free from magnesium salts).

(i) *Commercial strongly acid chromate dips.* A representative bath of this class has been found to have very good buffering power over the working range (pH <0), curve 9, considerably better, in fact, than the buffering of the half-hour bath. This advantage is, however, considerably offset by the strong solvent action of the bath towards magnesium alloys.



Curve	Bath	Working range	Buffering Power gram/l. KOH
9	WELL BUFFERED BATHS Sodium dichromate + strong acid	<0	approx. 100
3	R.A.E. anodic bath (bath i of D.T.D. 911)	5.5-7.5	50
8	Strongly alkaline anodic baths	> 12	> 40
1B	R.A.E. hot half hour bath (bath iii of D.T.D. 911A) with ammonia loss	5.9-6.2	36
4H	Sodium dichromate + transitional metal sulphate, hot	3.8-5.8	35
2	R.A.E. cold immersion bath (bath ii of D.T.D. 911A)	3.1-4.2	19.5
4C	POORLY BUFFERED BATHS Sodium dichromate + transitional metal sulphate, cold	3.8-5.3	4.8
1A	R.A.E. hot half hour bath, no ammonia loss	5.9-6.2	1.7
6	Sodium dichromate + alkaline earth sulphate	3.9-5.4	1.0
5	Sodium dichromate + chromic acid + persulphate	2.1-4.5	0.7
7	Sodium dichromate + phosphate, anodic	4.0-4.8	0.5

Fig. 12.—Gross buffering power of commercial chromate baths.

## 11. Conclusions

The importance of good buffering in a commercial chromate bath for magnesium alloys has been discussed. Some of the baths described in the literature have been shown to be poorly buffered.

Perhaps as important as the purely technical approach is the insight into chemical reactions which can be gained by a study of pH curves, particularly those involving precipitation and re-solution. The curves can be used to illustrate chemical reactions; deductions concerning the reactions taking place and the composition of any precipitate can often be made and then checked by analysis. Such curves, in fact, can be to the chemist what the equilibrium diagram is to the metallurgist.

## Acknowledgments

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## "Green Arrow" Service Restored for Export Traffic

BRITISH RAILWAYS are to restore on March 1, 1951, the "Green Arrow" Registered Transits service for full wagon loads of freight traffic for export, except traffic to Ireland. The fee will be 5/- per consignment in addition to the usual carriage charges.

Under this scheme a full consignment of goods is registered through to the port; every railway contact point en route receives an advance advice, by telephone or telegraph, of the consignment's passage, and a constant watch is maintained until the goods are finally delivered. The sender can also ascertain in advance when delivery can be effected. Each consignment sent under this service is labelled with a "Green Arrow" label which identifies it throughout its journey.

# The Effect of Isothermal Treatment on the Mechanical Properties of Steel

With a Note on Solder Embrittlement

By M. Douglas Jepson, Ph.D.\*

*Although the literature concerning the mechanism of the isothermal transformation of austenite is exceedingly voluminous, relatively few investigations have been carried out on the mechanical properties of isothermally transformed steels. In this article, comparison is made between isothermally transformed material (tempered in some cases) and quenched and tempered specimens. The results show the isothermal treatment to have an advantage, but the marked inferiority exhibited by the quenched samples tempered at temperatures below 300° C was found to be due to embrittlement by the molten solder of the tempering bath.*

THE decomposition of austenite under isothermal conditions has been under investigation for many years, but the great majority of this work has been concerned with the nature and mechanism of the transformation. Relatively few investigations have been carried out on the mechanical properties of isothermally transformed steel and even these results have tended to be somewhat contradictory.

The first important work was that of Davenport and Bain<sup>1</sup> who claimed improved properties (especially impact strength) due to this treatment. Later, the same workers<sup>2</sup> showed that this was due to the absence of micro-cracks, which are produced by quenching, in the isothermally transformed steel. Cottrell<sup>3</sup> examined the tensile properties of an air-hardening steel during transformation, but these results are not really comparable.

The present work is, in part, a repetition of some of this earlier work but, in addition, the effect of tempering on previously isothermally transformed material is investigated.

## Material and Treatment

The steel used in these experiments, steel A, was in the form of patented wire, 0.16 in. diameter. It was in the hard drawn condition, and was therefore annealed at 800° C. under carbon before cutting into specimens. The percentage composition was:—

C	Si	Mn	P	S	Ni	Cr	Cu
0.84	0.22	0.53	0.033	0.049	0.12	0.09	0.12

The treatment investigated consisted in heating the specimen to 800° C., in a slow stream of nitrogen, followed by:—

(a) water quenching and tempering at temperatures between 150° and 600° C.; or,

(b) oil quenching and tempering within the same range; or,

(c) isothermal transformation at temperatures between 150° and 600° C.; or,

(d) isothermal transformation at temperatures between 150° and 400° C., followed by tempering at temperatures in the range 400°–600° C.

The specimens, 1½ in. long for the bend, and 2½ in. for the tensile test, were fixed to lengths of 18-gauge steel wire, by means of fine nickel-chromium wire, to

facilitate transfer from furnace to furnace, the transfer being carried out by hand and taking about one second.

After the treatments were complete, the specimens were quenched in water.

## Mechanical Testing

The mechanical tests to which the samples were subjected comprised:—

- (1) A slow bend test on a notched bar;
- (2) Hardness test; and
- (3) Tensile test.

It was originally intended to measure the notch-toughness of the specimens by an impact test, using a small, Izod-type machine. A series of trial tests made on a specially prepared series of specimens showed, however, that all the values recorded were between 0 and 1 ft.-lb. Since this range was represented by only 3° of arc on the scale of the apparatus, it was clear that this test could not give results of any value.

As an alternative, the possibilities of a slow bend test were examined. A series of trial samples gave results of a suitable order, the range of breaking load of the notched bars varying from 0.02–0.3 tons on a scale ranging from 0–0.5 tons.

A Hounsfield 'Tensometer,' Type A, was employed, using the special grips provided, the specimens having a notch cut half-way along the length. This notch was cut by a fine copper wire (22 s.w.g.) loaded with carborundum, stretched over a light steel frame and used as a saw. It was, therefore, of U form, having a semi-circular root of 0.019-in. radius, the depth being fixed by a small gauge at 0.021-in. A sharper notch was unsuitable for the present purpose, as with it the results were far less discriminating.

The load was applied at the back of the specimen by a knife-edge located behind the notch. From the autographic record, by measuring the area under the curve, i.e., the product of the load and the deflection of the specimen, a measure of the work done to break the latter was determined. This may be taken as an indication of the notch-toughness of the specimen, but the value is, unfortunately, merely comparative.

The Vickers hardness tests were carried out with the standard machine, the average of three indentations being taken.

The Hounsfield Tensometer was also used for the tensile tests, the maximum stress alone being measured, since the lack of any 'test length,' and the very brittle

\* Formerly of Manchester University.

1 Davenport and Bain, *Amer. Inst. Min. and Met. Eng.*, 1930, **90**, p. 117.

2 Davenport, Hoff and Bain, *Amer. Soc. Metals*, 1934, **22**, p. 249.

3 Cottrell, *Jnl. Iron and Steel Inst.*, 1945, No. 1, p. 92.

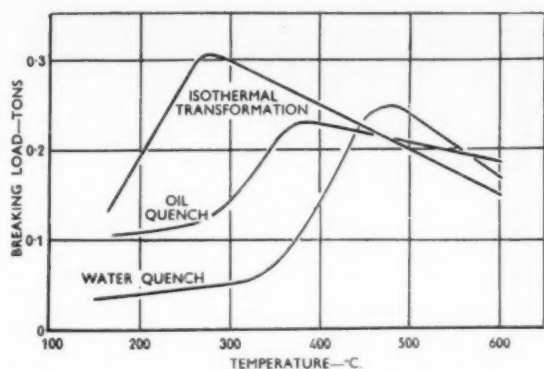


Fig. 1a.—Notch-bend test. Breaking load v. transformation temperature.

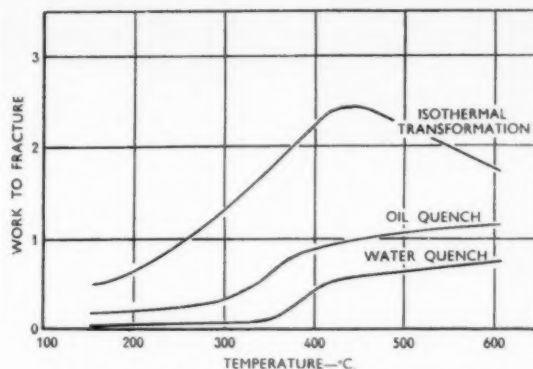


Fig. 1b.—Notch-bend test. Work to fracture v. transformation temperature.

Fig. 2a (left).—Vickers hardness v. transformation temperature.

Fig. 2b (right).—Vickers hardness v. tempering temperature.

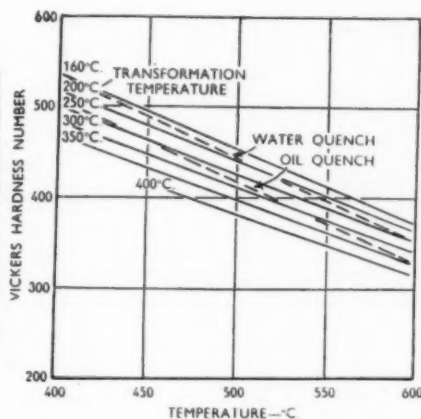
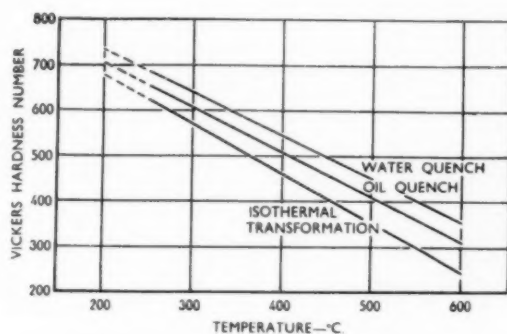
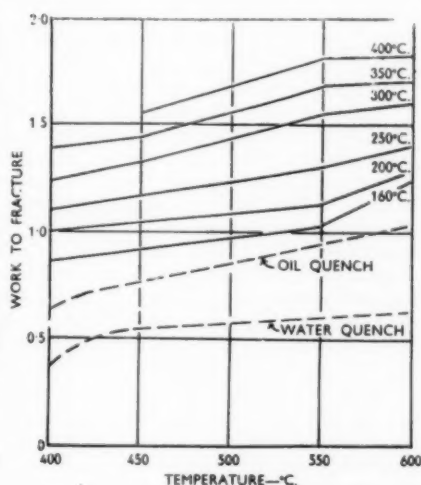
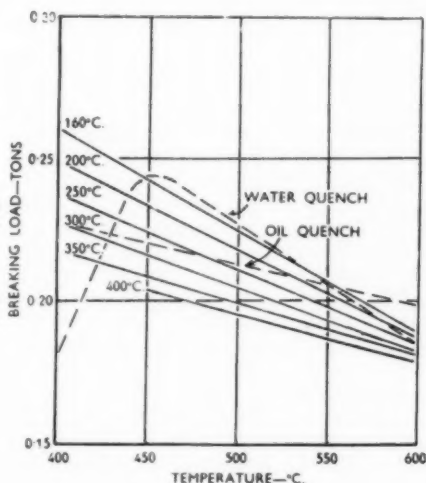


Fig. 3a (left).—Notch-bend test. Breaking load v. tempering temperature.

Fig. 3b (right).—Notch-bend test. Work to fracture v. tempering temperature.



nature of most of the specimens, rendered the determination of the elongation or reduction of area impracticable. The results obtained from these tensile tests proved to be generally unsatisfactory, due to a number of factors.

(1) The specimens were of uniform cross-section and had to be held in "wire" grips, the serration of which tended to damage the specimen, causing premature failure.

(2) In spite of most careful attempts to straighten the wire prior to heat-treatment, the specimens were not perfectly straight, and when pulled straight as the grips tightened, the brittle specimens again tended to break prematurely.

(3) A number of the more ductile specimens, or perhaps more correctly, certain of these free from



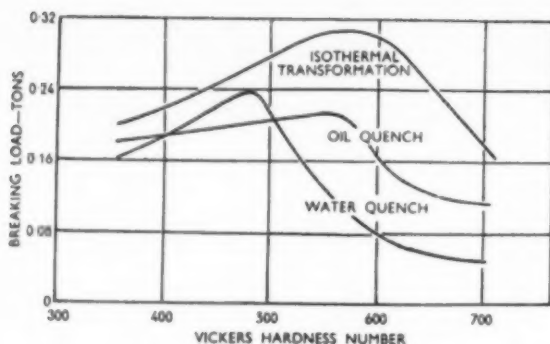


Fig. 4a.—Notch-bend test. Breaking load v. Vickers hardness.

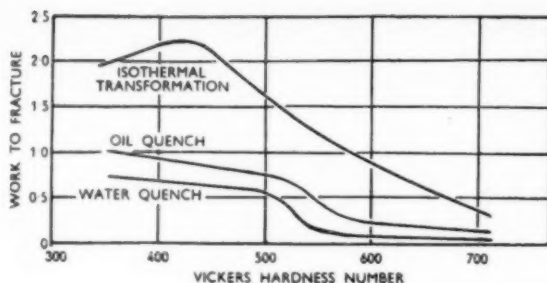


Fig. 4b.—Notch-bend test. Work to fracture v. Vickers hardness.

internal cracks, were found to have tensile strengths in excess of 100 tons/sq. in., which was the limit of the machine employed.

#### Consideration of Results

The results for the slow-bend and hardness tests are given in full in Tables I, II and III and plotted in Figs. 1 to 5.

Comparison was first made on a temperature basis, the properties resulting from isothermal transformation at a given bath temperature, say  $A^{\circ}\text{C}$ ., being compared with those of quenched material tempered at  $A^{\circ}\text{C}$ . That is, on a basis of transformation temperature. The temperature scale in Figs. 1 and 2a refers then to the metal bath temperature in the case of isothermal transformation and to the tempering temperature of the quenched and tempered specimens.

In Figs. 2b, 3 and 5, the temperatures adjacent to each isothermal curve indicate the temperatures at which isothermal transformation had been carried out, prior to tempering. The temperature scale in Figs. 2b and 3 referring to the temperature of this subsequent tempering.

As equivalent hardness was believed to be a more satisfactory basis of comparison than transformation temperature, the curves shown in Fig. 5 were derived from the results already plotted in Figs. 2b and 3. With regard to Fig. 5a, it was found that in replotting on a hardness basis the separate curves for each transformation temperature ran very close together. The total variation was only of the order of 2%, and the results for all transformation temperatures are, therefore, shown as one curve.

For this type of heat-treatment, therefore, any pairs of quenching and tempering temperatures which between them produce a given hardness, will give the same breaking load, although not of course, the same notch-toughness (see Fig. 5b). The oil- and water-quenched and tempered curves lie close to that already discussed.

For the reasons already stated, the results of the tensile tests were, in the main, unsatisfactory, and have not, therefore, been included.

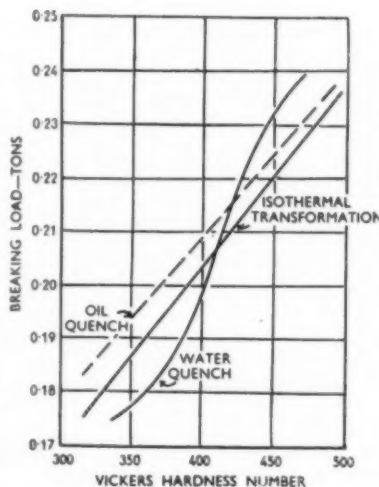


Fig. 5a.—Notch-bend test. Breaking load v. Vickers hardness.

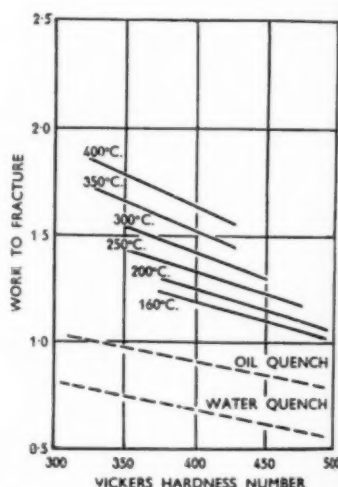


Fig. 5b.—Notch-bend test. Work to fracture v. Vickers hardness.

In the discussion of the results, then, only the slow-bend and the hardness tests will be considered, but the remarks about internal cracking are very relevant to the tensile test.

It is realised that the preliminary work, involving a comparison of the properties resulting from direct isothermal transformation with those from quenching and tempering treatments, Figs. 1 and 4, is not new. It was, however, felt advisable to include it in order to give a more complete picture of the scope of the work. The author would wish to place more emphasis on the effects of tempering the isothermal product, as being of considerable interest.

The results show very clearly the marked advantage of isothermal heat-treatment as compared with the more usual quenching and tempering, so far, at any rate, as this steel and this particular test are concerned.

#### Micro-cracking

A feature of the results is the exceedingly low notch-toughness after quenching and tempering at temperatures below  $300^{\circ}\text{C}$ . Nearly all the specimens in this category were found to contain numerous fine, radial

*Continued on page 81*

# Aluminium Supply and Demand

## Development of New Applications Likely to be Retarded

*While the situation is not yet such as to call for the conversion of pots and pans into Spitfires, the need for directing a greater amount of aluminium to the satisfying of defence demands is likely to lead to a curtailment of supplies for less essential purposes. Closing down of a number of reduction plants after the war, stockpiling, defence needs and dollar requirements have all played their part in producing the atmosphere of uncertainty in which the future of the aluminium industry is shrouded.*

LESS than six months ago, on the occasion of the opening of the Northern Aluminium Company's new continuous strip rolling mill at Rogerstone, by the Minister of Supply, the headlines of the national press were forecasting that the supply of pots and pans would soon be more plentiful and at a lower price. How different is the situation in which we find ourselves to-day, with a considerable air of uncertainty shrouding the future of the aluminium industry and the feeling that pots and pans will have to take a back seat in order to make way, once more, for Spitfires or their present-day counterparts. Thus has the aluminium industry to change again the direction of its progress, in order to satisfy the needs of the times. During the war years, the aluminium fabricating capacity of this country was increased enormously to provide the sheets, extrusions, forgings and castings necessary to meet the needs of the armed services, particularly, of course, of the Royal Air Force. It was felt by many, as the war drew to its close, that the aluminium fabricating industry was in for a very difficult time in attempting to create sufficient demand for its products to keep a high percentage, if not all, of its capacity in production. Nevertheless, the industry tackled the problem with the same forceful purpose as it had earlier tackled the converse problem—that of increasing output to meet the needs of the aircraft industry in wartime. The success which attended the drive to find new uses for aluminium and its alloys was truly remarkable, particularly in the field of building, where extruded sections and both flat and corrugated sheet have found numerous applications. This would not have been possible without the strenuous efforts made by the industry to reduce costs by the adoption of the most up-to-date production methods and equipment and by the standardisation of products wherever possible. As a result of these efforts, the cost of aluminium is little more than it was twenty years ago, whilst the cost of many other materials has risen enormously. It must be admitted, of course, that shortages of other materials, particularly steel and timber, in the immediate post-war period, had a considerable bearing on the acceptance of aluminium for purposes for which it had been comparatively little used before 1939. Nevertheless, it will be readily conceded that the industry has done an exceptionally fine job in surmounting its post-war difficulties. What a disappointment it must be, therefore, to see a state of affairs in which so much of that good work may easily be set at nought as a result of a limitation of the amount of aluminium available. It is not just a question of having to reduce the output available for established fields; it may involve withdrawal from what seemed likely to prove promising fields of development.

Whilst the foregoing is undoubtedly true, the situation does not appear quite so gloomy as seemed likely in

November. This is not to suggest that there will be aluminium in plenty for any and every requirement—there will certainly be an excess of demand over supply, but it is unlikely that the shortage will be so severe as in certain other non-ferrous metals. On the other hand there seems little prospect of there being sufficient aluminium for it to be used as a substitute for those metals which are in short supply, so that although there will be fresh fields to conquer, victory will be unattainable due to a relative shortage of aluminium.

### The Origins of the Shortage

In considering the supply position, it must be borne in mind that Britain produces something of the order of one-sixth of her virgin aluminium requirements, the remainder being imported, mainly from Canada. Soon after the end of the war, it seemed unlikely that the high level of output of virgin metal achieved at the peak of wartime production, 1943-44, could be absorbed in peace-time uses until new applications had been established over a period of several years. As a result the Canadian production was curtailed to some 300,000 tons a year, and the resulting power surplus was diverted to the development programme of other industries—a process which did not allow of easy reversal. Simultaneously the uncertainty of virgin metal prices resulted in the closing down of certain uneconomic United States plants which had been operated during the war. A further factor affecting the supply position is the stockpiling activities of the United States Government, undertaken as a result of the uncertainty of the international situation. As far as this country is concerned, the reluctance to spend dollars on virgin metal imports when they were more readily available must also be taken into account.

### The Present Position

For the last two years, the virgin aluminium consumption in Britain has been in the region of 180,000 tons and to this must be added a consumption of 70,000 tons of secondary aluminium. Immediately after the war there were large amounts of scrap for the production of secondary aluminium on which the castings side of the industry depends to a considerable extent. Indeed, at the time, it was expected that this scrap might become a source of embarrassment; in actual fact it has proved a very useful source of raw material but stocks are now considerably diminished and it is by no means certain that the foundries will be able to obtain such a high percentage of their requirements from secondary metal. This will, naturally, entail further demands on the virgin metal supplies. Last summer the Ministry of Supply made one of its usual annual contracts with the Canadians, ordering 150,000 tons for 1951. On December

18, it was announced that arrangements had been made with the Aluminium Company of Canada, Ltd. for an additional 50,000 tons in 1951 in addition to the 150,000 tons already contracted for, and for the supply in 1952 and 1953 of 220,000 tons per annum. The British Government has agreed to fund afresh over a period of 20 years the loans made to the Company during the war to finance the expansion of capacity in Canada, and to make a new loan of 25 million dollars towards the financing of further expansion. The Company will give the British Government first call on 200,000 tons per annum of its production for 20 years. In this way provision has been made for the rising requirements of defence and for essential civilian production and is the basis for the more promising supply outlook, although it must be emphasised that this does not mean that supplies to industry will be unrestricted. In an article in the *Financial Times* it is pointed out that in the first six months of 1950 when industry could obtain all it wanted, the consumption of virgin aluminium was at the rate of 13,800 tons per month. By September, it became clear that unrestricted requirements would amount to a consumption of 20,000 tons per month. The Ministry of Supply agreed to release 51,000 tons for the last quarter of the year, but emphasised that in the early months of 1951 supplies would have to be cut to 15,000 tons a month. By this time, even without rearmament it seemed likely that consumption would reach 23,000 tons per month if sufficient metal were available. It is clear, therefore, that severe cuts in certain forms of consumption will have to be made.

#### The Immediate Future

At present it is impossible, in the absence of an official estimate, to say what proportion of output will have to be diverted from normal civilian uses to defence orders; it may, perhaps, be something of the order of 20-30% of present output. Some scheme will have to be worked out to see where such cuts should be made in the best interests of the nation. It would be quite impracticable, for several reasons, to ration all consumers of aluminium, to a uniform proportion of their 1950 consumption. In the first place, some of the most important uses of aluminium are in products which are essential from a national point of view, e.g. commercial road vehicles. Secondly, the fabricating industry has very important export markets and it is estimated that at least 60% of the current output is exported directly by fabricators or indirectly in the form of manufactured goods, e.g. packaging. Furthermore, in recent years, close attention has been paid by the industry to the development of the use of aluminium in a wide range of industries where it has specific advantages over alternative materials, e.g. in moving structures, rail transport and ships superstructures. There is little doubt that the fabricating industry will try to ensure that supplies for such developments are maintained.

Direct exports of fabricated aluminium have been running at about £12 million per year and it is felt that there may have to be a reduction in this amount. In effect, Commonwealth countries and other buyers will be asked to share in the austerity imposed on home usage of aluminium. As has been mentioned earlier, considerable progress has been made in the use of aluminium in the building trade, which accounts for 18% of the home usage, in the form of roofing, guttering, rainwater goods, etc. In most of these cases, aluminium is an alternative

to other materials which are now in better supply than in the past and it seems that there are likely to be restrictions in this field of use. Without doubt there will be a reduction in the production of aluminium hollow ware, with favourable treatment being accorded to pipes and pans at the expense of less essential domestic articles.

In normal circumstances, the extra 50,000 tons of virgin aluminium to be obtained from Canada this year could relieve the situation considerably, but the call of the defence needs coupled with the desirability to rebuild the stocks—which are now being run down to allow industry 15,000 tons a month—make it impossible to assess the position with any degree of certainty.

#### Increasing Supplies

Home production of virgin aluminium is being increased from 30,000 tons to 35,000 tons a year, but in the process of conversion the current rate of production has been well below 30,000 tons. This increase is a very modest step compared with the grandiose schemes which are stated to be under discussion in America, where the 1950 production of 640,000 tons was some 19 per cent. higher than that for 1949, and was only exceeded in 1943 and 1944. By starting up several standby plants now being renovated, it is believed that output could probably be increased by 18% by the middle of this year. In order to encourage increased production the U.S. Government has promised producers that it will be responsible for the sale of the output of expanded factories for five years, either to industry or to the stockpile. Present plans call for the Aluminium Company of America to step up its production by 107,000 tons, and Reynolds Metal Company and Kaiser Aluminium Chemical by 90,000 tons each by 1952. Other negotiations in progress may swell the total expansion to 450,000 tons, i.e. an increase of some 70% of the 1950 production. It is understood that arrangements have also been made to bring the Canadian ingot capacity up to 350,000-400,000 tons. One point concerning these programmes which is not quite clear is the source of the by no means inconsiderable power which will be necessary for these increased outputs. Although the use of natural gas as a source of power is being considered in the States, hydro-electric power is generally regarded as being necessary for the economic extraction of aluminium and such schemes take an appreciable time to complete. It may be that the expansions are envisaged only in such circumstances that power would be available at the expense of other power consuming but less essential industries.

#### Metro-Cutanit's New Works

METRO-CUTANIT, LTD., have now acquired new factory premises at Grappenhall, near Warrington. Production will shortly be started at the new works, and some of the work at present being carried out at the existing factory at Allen Street, Warrington, will be transferred there. The acquisition of the new factory will enable expansion to be made in the production of cemented carbide tips and pieces, contact metals, resistance welding electrodes and hard-facing rods, and, in addition, to manufacture a wide range of special metals and metal parts by powder metallurgy.



## Secondary Aluminium Mission to the U.S.A.

THE mission of European experts which returned a few months ago, from a six weeks' study of secondary aluminium plants in the United States, and whose full report on the visit is in course of preparation, has issued a statement in which its main findings are summarised.

The purpose of the mission was to study the recovery of scrap aluminium in the United States, the production of secondary aluminium alloys and the use of scrap and secondary aluminium in cast and wrought products. The greater use of scrap and secondary aluminium would help to reduce total expenditure by Marshall Aid countries on dollar imports of primary aluminium, and would help to ease the present growing shortage.

During its stay in the United States the O.E.E.C. team visited some seven aluminium smelters, two brass and bronze smelters, two non-ferrous scrap dealers, eleven foundries (including sand, permanent-mould and pressure-die casting operations) four rolling mills, one extrusion and forging plant and one research laboratory. Individual experts visited additional smelters, sand foundries and rolling mills.

The Final Report of the mission is expected to be published shortly and to be circulated to the European industries concerned. The mission has meanwhile reached a number of tentative conclusions which it might be useful to state immediately. It should be stressed at this point that there is at present in the United States a severe shortage of aluminium scrap and secondary metal and that this may have temporarily modified the consumption pattern for secondary material in the United States.

### Smelting and Refining Operations

The most noteworthy difference from European practice in smelting operations is the almost general use of reverberatory type furnaces with external open wells as opposed to the closed reverberatory for normal scrap, the rotary for borings and to a lesser extent the low-frequency induction types used in Europe. The advantages of the open-well type of reverberatory is its high output and its great suitability for mechanical charging and handling. Largely (but perhaps not entirely) as a result of the different type of furnace, very much less flux is used in the smelting operation than in most European practice. Detailed study is necessary to decide the overall advantages of the open-wall furnace for European plants (possible disadvantages being lower rate of metal recovery, more difficult changeover from one alloy to another, etc.) and whether the much smaller amount of flux used affects the quality of the ingot, e.g., by a greater proportion of non-metallic inclusions.

As in Europe, no metallurgical refining other than the removal of magnesium is practised. Magnesium removal is effected largely with the use of fluxes of the aluminium fluoride group, though some chlorine treatment was also seen. The latter has, however, been discontinued in some plants owing to fume disposal difficulties. Nitrogen is normally preferred for degassing, though here again, occasional chlorine treatment was witnessed.

The general use of spectrographic analysis enables a rapid control of the melt to be carried out. Of especial interest has been the use of Quantometer control, whose speed and accuracy makes it almost ideal for analysis of

raw material and for control of melt composition. The economics of this type of instrument for European practice will have to be carefully studied, as well as possibilities of reducing dollar expenditure for obtaining this or similar equipment.

### Foundry and Rolling Mill Operations

Foundries producing castings buy very little scrap for direct use and depend almost entirely on purchased composition ingot for their raw material. This results in a much cleaner metal of more regular composition being used for the cast product, and in greatly simplified melting technique.

Foundries specialise considerably more than in most European countries in limited types and sizes of castings. This is combined with very careful planning for each individual run, of equipment, layout and operation.

Pressure die-cast products appear to represent a considerably greater proportion of the total output of castings than in Europe, no doubt as a result of the much greater demand and longer runs possible. Machines are usually of the same size, with several small castings being produced at one shot instead of using smaller machines.

The application of mechanical opening and closing of permanent-mould dies is very advanced and could lead to improvements in the economic efficiency of European operations.

Automatic regulation of melting furnace temperature and automatic cycle timing has been frequently observed. On the other hand, more disturbance of liquid metal is permitted in many American foundries than in Europe.

A considerable number of useful improvements in billet and slab casting and in rolling equipment and technique were witnessed which will be described in the Final Report. All but one of the rolling mills, however, operated only on primary material.

### Use of Secondary Material

The mission is of the opinion that, largely as a result of the differences between the American and European economy (the need to economise in labour on the one hand, and in raw material on the other), the percentage recovery of the metal content of scrap is higher in Europe than in the United States. Secondly, the mission considers that a somewhat larger percentage of secondary metal is being used in Europe than in the United States at the present time. This excludes absorption of scrap by primary producers, about which no up-to-date information was available.

The mission was shown no use of secondary metal for the manufacture of any wrought product except that of roofing and siding sheet. The latter market absorbs enormous quantities of metal, and as it is made from a low-grade alloy, a certain amount of downgrading of high-grade alloy scrap takes place in order to meet the demand. Some primary metal is, however, used in Europe, as in the United States, for roofing sheet, especially to meet export requirements, and the possibility of replacing this with secondary material in normal market conditions will be considered in detail.

In general, the mission has seen a considerable number of applications of aluminium, both primary and secondary, which are not as common in Europe as in the U.S.A. These applications, however, do not as a rule

replace the use of dollar costing materials such as copper.

With regard to alloy specifications, the maxima allowed in the United States for impurities (copper, zinc, etc.) are higher than in most European countries,

and this may be a factor in restricting the use by the latter of secondary metal for certain applications. More study of the effects of such greater amounts of impurities is necessary.

## Aluminium Survey Launch

A DEVELOPMENT of some importance is represented by the construction in aluminium of a 60 ft. survey launch for the Pakistan Government. Built by Grimston Astor, Ltd., of Bideford, the *Ain-Al-Bahr* recently underwent successful trials there. The vessel is intended for estuary work in East Pakistan and is designed to have an endurance of 1,500 miles, carrying food and water for three weeks for a crew of 15. Shallow draught and habitability are the essential characteristics of the new launch, both helped by the light structural weight achieved by the patented constructional method developed by the builders.

This method, known as "two-way tension," represents a radical departure from orthodox methods of construction, and results in a vessel with a "stressed skin." Instead of fitting contoured plates to a skeleton structure, the hull is built from large plates in a flat unstressed condition so that it can be flexed about the centre line into the shape of a complete boat having a rigid structure, conforming accurately to the pre-designed outline. Apart from a saving of some 60% of the weight of the hull, production costs are also reduced because most of the operations are repetition work which can be performed by unskilled labour. Furthermore, the space required to stack flat pre-fabricated parts is small and the tools and jigs are very simple. The space factor is also of importance where hulls are crated for export as, after fabrication and before folding up,



the hull occupies but a few inches in depth and a number can be stowed on top of each other in quite a shallow packing case.

Powered by twin diesel engines giving a top speed of 13 knots, the vessel, which has a beam of 14 ft. 6 in. has a draught of 2 ft. 9 in., and displacement of 11 tons, as compared with 4 ft. 6 in. and 70-75 tons for a similar vessel built in teak by a local yard in Pakistan. Furthermore, the wooden vessel needs 260 b.h.p. as against less than 130 b.h.p. for the same speed. The increased engine space and fuel requirements must reduce materially the space available for the crew. The *Ain-Al-Bahr* is built to Ministry of Transport (ex. B.O.T.) requirements, yet in spite of her light construction, easily passed the strength test required of the strongest lifeboats, which have to be hoisted by their ends with more than full load.

Material to specification A.W.5, supplied by the British Aluminium Co., Ltd., was widely used in the vessel's construction. The foredeck plating was formed in  $\frac{1}{8}$  in. light alloy positive-grip-pattern treadplate, while the rivets conformed to A.W.6. The three-bladed 16-in. diameter, and 11-in. pitch propellers were also made in light alloy.

Aluminium construction shows up particularly well in tropical service—the rapid deterioration of steel and wooden hulls placing them in a relatively inferior position. Terebo worm affects wooden craft and rapid drying after wetting results in rusting of steel craft at a rate which entails a large annual expenditure on maintenance. Under these conditions a higher first cost would be allowable for an aluminium boat, but one of the advantages of the method of construction used for the *Ain-Al-Bahr* is that first cost is actually considerably less than that of steel or wooden construction.



# Aluminium and its Alloys in 1950

## Some Aspects of Research and Technical Progress Reported

By E. Elliott, A.Met., A.I.M.

*Information Officer, Aluminium Development Association*

SCIENCE and technology, contrary to the popular view, achieve their ends, not by leaps and bounds, but by steady advance throughout the years, adding always to the eternally incomplete library of knowledge. With a few notable exceptions—such as 1886 in the case of aluminium—it would be difficult to label any particular year in the history of a metal as a period of revolutionary discovery, and, although technical progress in the aluminium field has followed this rule during the past year, many interesting and important articles and papers have been published.

### Production

It is well-known that the present method of extracting aluminium from its oxide differs little, in essentials, from that first used by Hall & Héroult, and no great advances have been reported during the year. A useful account of the extractive metallurgy of the metal, with references to other processes which have had some vogue, such as the German direct reduction method, was given by Sherwin<sup>1</sup> to the American Institute of Mining and Metallurgical Engineers. Luzzatto<sup>2</sup> has discussed at considerable length the electrolytic cells used in the extraction of aluminium from alumina. After analysing the electro-chemical and thermal aspects, he stresses the necessity for finding methods of reducing loss of heat from the cell, especially through its upper surface, and suggests that this may be achieved by the use of the improved self-baking electrodes that he describes. He goes so far as to foretell the cell of the future, which will be completely mechanised in operation, and employ improved methods of heat insulation and gas removal.

Hitherto, apart from times of emergency such as the late war, only hydro-electricity has been considered sufficiently cheap for aluminium production, and considerable interest has been aroused by the decision of the Aluminium Company of America to employ natural gas as a source of power at their reduction works at Point Comfort in Texas.<sup>3</sup> In view of the great unsatisfied world demand for cheap power for aluminium smelters, and the high capital cost of providing hydro-electric stations, this development will be followed with interest.

### Melting and Casting

Although the date on the title page is 1949, Panseri's<sup>4</sup> exhaustive treatise on aluminium in the foundry did not reach readers in this country until 1950. It fulfils a long-felt want for a really comprehensive book on the production of aluminium alloy castings, and it is unfortunate that the language difficulty will limit the number of its readers here. This particular trouble does not arise in connection with the interesting article on multiple continuous casting by Helling & Gassner,<sup>5</sup> which has appeared in translation. Their method, employing a heated launder, is claimed to result in appreciable savings in manpower and materials, and even in some cases the elimination of extrusion as a step in the manufacture of certain products.

Ruddle<sup>6,7</sup> has published two papers describing his fundamental investigations into the mode of solidification of castings, and much of this work has been carried out on aluminium and its alloys. His technique is based on the very accurate measurement of temperature in cooling castings and he describes two distinct processes of solidification, to which he gives the terms "skin formation" and the "pasty" method. The former is shown to obtain with pure metals and some eutectiferous alloys, and the latter with solid-solution alloys. It is particularly interesting that not all the eutectiferous alloys tested solidify by "skin formation"; while the mechanism is as yet obscure, the aluminium-13% silicon alloy, amongst others, apparently approaches the "pasty" type.

Using the accurate methods of temperature measurement described in the papers referred to above, Ruddle<sup>8</sup> has studied the relationship between the temperature gradients during solidification and the subsequent tensile properties of cast plates in aluminium-4½% copper alloy. He shows that, with rapid pouring, ½ in. plates have the highest longitudinal temperature gradients of the range ¼–1½ in. thickness, and, moreover, also possess the highest soundness and tensile properties. He draws the general conclusion that with aluminium alloys of long freezing range, high tensile properties depend upon the magnitude of the axial temperature gradients present during solidification, particularly at the later stages when interdendritic feeding is taking place.

Considerable attention has been devoted recently to the factors which influence grain refinement in aluminium and its alloys, and an interesting point which emerges from work by Kondic & Shutt<sup>9</sup> is the effect of nuclei on cast structure. Whereas, with super-pure aluminium, the heating and cooling of the molten metal is the main influence on the cast macrostructure obtained, with the commercially pure metal, in a range of superheating temperatures up to 20–25° C. above the liquidus, residual nuclei are the major factor. Moreover, foreign nuclei are shown to play the greatest part in grain-refinement of aluminium of both purities, mechanical disturbance and rate of cooling being less important.

### Working

Special reference must be made to the Symposium on Metallurgical Aspects of the Hot Working of Non-Ferrous Metals and Alloys, held by the Institute of Metals during the year. Three of the papers were devoted to the hot-working of aluminium and its alloys, and each forms a very useful review of present practice in the field covered. Kasz & Varley<sup>10</sup> discuss at length the physical and metallurgical aspects of hot-rolling, and suggest that, in the case of aluminium, the metal behaves as a very viscous fluid, and that while there is no roll-face slip, there is considerable relative movement of the various layers of the metal. This last is neatly demonstrated by inserting wires of aluminium-copper alloy in



pure aluminium rolling slabs, normal to the direction of rolling, and revealing them by etching after rolling. The influence of hot-rolling variables on the finally cold-rolled sheet are also considered.

Smith<sup>11</sup> gives an extremely clear exposition of the extrusion process and the way in which the nature of the flow which occurs affects die design and manufacture. The problems associated with extruding heat-treated alloys are discussed, and the various effects of extrusion on the properties of the product are explained. Stokeld<sup>12</sup> points out the differences in hot forging practice between steels and aluminium alloys, and stresses the difficulties of assessing the properties of forgings at different locations in their shape. The effect of many variables on this problem is considered at some length.

The cold shearing of metal bars is a subject which has not received much technical investigation, and a paper on the subject by Chang & Swift<sup>13</sup> is the more welcome for that reason. Among other metals, aluminium was tested, and behaved as a soft metal in that for clean cutting the optimum clearance was found to be zero. The mechanism of shearing and the effect of tool condition is discussed. No correlation could be found between shearing stresses and tensile strength.

### Joining

The soldering of aluminium is a process about which many misconceptions exist, and it has recently been brought into prominence by its successful use in the joining of aluminium-sheathed power cables, for which a recommended technique has been laid down. No major research on the soldering of aluminium has been reported, and an account by Roberts<sup>14</sup> of a limited number of tests on six different solders is therefore of special interest. Joining was effected by "friction soldering," without the use of flux, and corrosion tests on the resulting composite specimens are described. These confirmed the general view that solders containing a very high proportion of zinc (95% in this case) are the most satisfactory in producing a corrosion-resistant joint, high tin alloys being less suitable in this respect. It is also noteworthy that the high zinc alloys "tinned" the aluminium the most readily of the solder tested, and gave joint strengths equal to that of the soft aluminium sheet used in the experiments.

Noltingk and Neppiras<sup>15</sup> have investigated the mechanism of the tinning of aluminium with solder under the influence of ultrasonic vibration, and have concluded that a process of cavitation erosion removes the oxide film. It is understood that commercial development of this technique is proceeding.

The penetration of metals by solders causing weakness and embrittlement has long been recognised as a danger, and experiments recently reported<sup>16</sup> reveal that certain aluminium alloys can, under some conditions, suffer in this way. Pure aluminium and the aluminium-1½% manganese alloy are virtually free from this phenomenon, and also the aluminium-magnesium alloys containing 2½ and 3½% magnesium in the annealed condition. These alloys in the cold-worked condition, and heat-treated alloys, particularly when fully heat-treated, were shown to be liable, to some extent, to embrittlement by solder penetration.

Recent years have seen a considerable increase in the application of brazing to aluminium and some of its alloys, both wrought and cast. A short review of the process has been published by Palmer<sup>17</sup>, covering alloys

most suitable for joining by this method, brazing alloys, fluxes, technique and the limitations of the method. Magnesium contents above about 2% in the parent metal render brazing very difficult, and with heat-treated or work-hardened materials the effect of heating for brazing is to produce the annealed condition either locally, with torch brazing, or generally, in the case of flux-dip or furnace brazing.

A comparison has been made by Brandt<sup>18</sup> of the flash welding of non-ferrous and ferrous metals, and he tabulates machine settings and results for a number of aluminium alloys, and also for the joining of commercial purity aluminium to copper. Nipper<sup>19</sup> and his collaborators have described a lengthy investigation of the effect of flash-welding variables on temperature distribution, upset-pressure requirements and mechanical properties of completed welds, for two duralumin-type alloys, an aluminium-magnesium silicide alloy and an aluminium-zinc-magnesium-copper alloy. Joint efficiencies of nearly 100% are claimed for all these materials, and the order of sensitivity to over-ageing is stated to be greatest for the magnesium silicide type and least for the zinc-containing alloy.

The most important recent advance in the fusion welding of aluminium and its alloys is generally acknowledged to be the introduction of the argon-arc method. While the best-known version of this process is that which employs a tungsten electrode and a separate filler rod, there has been rapid progress in the United States in the adoption of the type of equipment in which the filler rod is itself the electrode, and is automatically fed into the arc as welding proceeds. Muller, Gibson and Roper<sup>20</sup> have provided an interesting account of this process, as used by hand and with an automatic welding head, and of its application to aluminium, amongst other metals; valuable data on welding conditions are included. Advantages of this method of welding over that with the tungsten electrode include increased speed of working and the facilitation of welding in positions not easy of access. It is noteworthy that, with aluminium, porosity in the weld metal due to hydrogen is a defect most difficult to eliminate except in the case of horizontal welding.

Work on the electrical characteristics of the argon-arc process has been described by Orton<sup>21</sup> and his co-workers, who used oscillographic methods to study certain electrical parameters involved. Some attention is also devoted to operational adjustments to the spark injector unit for satisfactory welding.

A considerable amount of research is in progress in this country and elsewhere on the manufacture and driving of large aluminium alloy rivets, and during the year Anders and Elliot<sup>22</sup> have read before the Engineering Institute of Canada a paper summarising recent developments in that country, principally in connection with the fabrication and erection of the aluminium bridge over the Saguenay River at Arvida, Quebec. The most interesting advance is the use of what the authors call the annular head, a recessed rivet head driven by a set of special shape, enabling the cold closing by pneumatic gun of rivets ¾ in. diameter and larger. In his 1950 James Forrest lecture<sup>23</sup> Sir Donald Bailey referred to a similar development in this country of which a full account may soon be expected.

### Constitution

A monumental and profusely illustrated paper appeared during the year describing extensive work by



the late Gosta Phragmen<sup>24</sup>, of Stockholm, on the constitution of a large range of aluminium alloys. Microscopic and X-ray crystallographic studies are described and ternary, quaternary, quinary and senary alloys are studied. In addition to theoretical considerations, the phases occurring in some commercially important alloys of aluminium with copper, magnesium, manganese, iron and silicon are discussed.

Ransley & Neufeld<sup>25</sup> have measured directly the solid solubility of sodium in aluminium at elevated temperatures, and also the solubility of sodium in liquid aluminium. In the presence of silicon, a ternary compound is formed; suggestions as to its composition are made, and a tentative aluminium-silicon-sodium diagram put forward. A novel method has been used by Thall and Chalmers<sup>26</sup> to make semi-quantitative determinations of the sodium content of aluminium-silicon alloys in their study of the phenomenon of modification. They employed a radio-active technique, taking advantage of the fact that when an aluminium-silicon-sodium alloy is exposed to a neutron flux, the isotope Na<sup>23</sup> is gradually converted to a radio-active isotope Na<sup>24</sup>, which subsequently decays with the evolution of  $\beta$  and  $\gamma$  rays. By measuring the  $\gamma$  radiation by means of a Geiger-Muller counter, a comparison of the sodium contents of various samples was made. The authors put forward a new theory of modification, based on the influence of sodium on the balance of inter-facial tensions during solidification.

### Properties

A communication from Thorpe<sup>27</sup> and his co-workers at the National Physical Laboratory describes a large number of routine tests on commercial and experimental alloys used in the construction of aero engines. Tensile, fatigue and creep tests at temperatures between 20° C. and 450° C. on seventeen wrought and seven cast alloys have been carried out, and a general comparison made of the materials on the basis of their properties at service temperatures. At 250° C. RR57-type alloy was found to be the most resistant to creep, and an experimental wrought alloy containing 10% silicon and 5% copper, with 0.3% cobalt, to have the highest fatigue strength.

Three papers on investigations into the mechanism and nature of creep should be mentioned because aluminium is used in the work described. Wood & Scrutton<sup>28</sup>, using super-purity aluminium, have studied in detail the process of breakdown of grains during deformation at elevated temperatures which precedes the establishment of secondary creep. They postulate the theory that primary creep is the resultant of two mechanisms, grain dissociation with structural disorder at higher rates of strain, and a similar dissociation with no disordering at lower rates. The former produces softening of the metal, and the latter hardening, until the equilibrium of secondary creep is reached. Greenough & Smith<sup>29</sup>, using super-purity and commercial purity aluminium, together with lead, have used X-ray methods to explain, in terms of dislocation theory, earlier observations by Wood and his collaborators on the mechanism of deformation in metals. Again using aluminium, this time of 99.4% purity, Calnan & Burns<sup>30</sup> have taken back-reflection Laue patterns of a large-grained test piece after successive amounts of creep deformation at 250° C. They conclude that creep, up to about 3% extension in 170 hours, is associated with slip

processes, and deformation is unhomogeneous even within the grains themselves, giving a coarse sub-structure. Continued extension results in the production of numerous fine cells from previously distorted material.

Further information on the high temperature mechanical properties of aluminium alloys has been provided by the British Non-Ferrous Metals Research Association. McKeown<sup>31</sup> has reported tensile tests at elevated temperatures on forged bars in DTD.364A and RR.59-type alloy, with and without intermediate extrusion. The results show that these materials begin to soften at about 175° C. so that the ultimate tensile strength obtained at these temperatures depends upon the time of soaking. Together with co-workers, McKeown<sup>32</sup> has also communicated the results of fatigue tests at elevated temperatures on four aluminium casting alloys, equivalent to LM6, LM4, LM14 and LM13 in B.S.1490. While with the aluminium-12% silicon alloy there appears to be a gradual and continuous drop in the value of the endurance limit with increase in temperature, with the other three no noticeable decrease is observed below 200° C.

From America have come a number of papers on various theoretical considerations in the properties of aluminium and its alloys. Rosi and Mathewson<sup>33</sup> have studied the plastic properties of single crystals of super-purity aluminium, particularly in shear. The critical shear stress was found to decrease exponentially with increase in temperature, while the coefficient of shear-hardening and the density of slip bands decreased parabolically at the same time. This indicates that the high rate of shear-hardening at low temperatures is associated with the more widespread distribution of deformation by slip, and suggests a maximum amount of shear within each slip band which is dependent on temperature. Banerjee<sup>34</sup> has also studied strain markings in super-purity aluminium, and gives evidence of a close relationship between them and annealing twins.

It is somewhat unusual to find that one of the references in a metallurgical paper is to an essay by Francis Bacon, but Dorn<sup>35</sup> and his collaborators introduce an account of an investigation into the effect of alloying elements on the properties of aluminium alloys by remarking that their results confirm the essayist's statement that "an alloy . . . will make the purer but softer metal capable of longer life." The work is largely fundamental, and the main conclusion reached is that the amount of solid solution hardening is dictated by two factors: the lattice strain, and the change in mean number of free electrons per atom of the solid solution.

Hardy<sup>36</sup> has studied the effect of very small proportions of a number of metals on the ageing characteristics of a high purity aluminium-4% copper alloy, cast and solution treated. Of the elements tested, those which dissolve in aluminium depress the natural ageing tendency, but considerably accelerate precipitation on heat-treatment; the insoluble elements have no such effects. A theoretical explanation of the phenomena observed is put forward.

From the classic work of Beilby to the present investigations of Bowden, a continuing keen interest has been taken by metallurgists in the surface properties of metals, and Owen and Liu have made a special study of the surface of super-purity aluminium. They confirm that the crystals of the immediate surface of the metal, after polishing, are in a state of strain, until relieved by

heat-treatment, but some room-temperature re-crystallisation occurs, the amount varying with the polishing medium. A note on the effect of surface scratches is appended.

As so much of the increased knowledge about the properties of aluminium and its alloys is the result of co-operative research, it is gratifying to read of the additional facilities and space acquired by the British Non-Ferrous Metals Research Association<sup>37</sup>. An interesting account of the Association's equipment for and methods of creep and fatigue testing has also been provided by McKeown<sup>38</sup>.

### Low Temperature Properties

The first of a series of monographs published under the authority of the Royal Aeronautical Society has appeared during the year; it is by Teed<sup>39</sup> on the low temperature properties of metals. With advance in aeronautics resulting in the use of aircraft at high altitudes, the importance of the low temperature properties of aluminium alloys increases, and this thorough critical survey of the literature is most welcome. It does, however, reveal the large gaps in our knowledge and should stimulate attempts to close as many as possible of them.

### Corrosion

Three important papers by members of the staff of the British Non-Ferrous Metals Research Association appeared during the year, concerned with stress corrosion. Aluminium alloys were used for this fundamental work as they provided readily-available examples of alloys with two phases differing electrochemically. Perryman and Hadden<sup>40</sup> have determined the stress-corrosion properties of commercial-purity aluminium-7% magnesium alloy after various thermal ageing treatments, and have demonstrated a close correlation between susceptibility to this form of attack in salt-spray tests and the form of occurrence of the  $\beta$  phase in this alloy. When the  $\beta$  material is present as a continuous grain-boundary precipitate, susceptibility is highest, but the alloy may be liable to stress-corrosion even when the phase occurs as separate "lakes," but only after ageing at high temperatures. Important points brought out are that cold work before ageing increases the rate of precipitation, while small additions of zinc have the reverse effect.

The latter of the above authors, in collaboration this time with Gilbert,<sup>41</sup> has published a closely argued theory to explain the behaviour observed in the practical tests. This postulates distinct stages in the attack: namely, the formation of crevices by the preferential solution of the  $\beta$  phase, stress concentration at one of these leading to partial fracture, rapid corrosion of the  $\beta$  surfaces exposed, and then a period of slower attack leading to the formation of further crevices. Repetition of the whole process follows until complete fracture occurs.

The aluminium-zinc alloys have been considered as of considerable interest in that they have appeared to be exceptions to the rule that aluminium alloys susceptible to stress corrosion contain two or more phases differing in electro chemical properties. Perryman and Blade<sup>42</sup> have shown, however, by examination of microstructures of aluminium-10%-zinc alloy, aged at room temperature and temperatures up to 125°C., that this ageing is accompanied by the formation at grain boundaries of

zinc-rich particles and a phase thought to be the aluminium-zinc solid solution stable at the temperature of ageing. Sustained tensile stress on this alloy results in intercrystalline fracture, the rate of which is enhanced by spraying with salt solution, and the authors put forward an argument that this failure is due to stress-corrosion, basing their theory on the electro-chemical properties of the precipitated phases.

All these papers from the B.N.F.M.R.A. are marked by the excellent photomicrographs which illustrate them.

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# The Aluminium Casting Alloy D.T.D.424<sup>\*</sup>

## (now known as LM-4.)

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(Communication from the British Non-Ferrous Metals' Research Association)

*The secondary aluminium-base alloy D.T.D.424 (now LM-4) was used extensively during the war as a substitute for alloys made from virgin materials, which were then in short supply. The alloy has proved to be an excellent one for general castings, and this article deals with the influence of melting procedure and additions on the properties of material made from swarf, skimmings and virgin metals, the effects of grain size and gas content, and heat treatment.*

### Part I

#### The Influence of Manufacturing Procedure on Properties

The light aluminium alloy commonly designated "D.T.D.424," introduced in 1939 and in its early years regarded as a wartime substitute material, proved to be an excellent foundry alloy giving castings of good properties. It is now a well-established material and is widely used and has been described by G. D. Chapman<sup>1</sup> as "the best all-round aluminium alloy for general foundry work." The high level of its casting characteristics and general properties is indicated in a recent Aluminium Development Association publication.<sup>2</sup> D.T.D.424 was first developed by the late Mr. Percy Pritchard<sup>3</sup> in anticipation of the situation likely to arise when large quantities of scrap of Duralumin-type and similar alloys would accumulate as a consequence of the manufacture and use of aircraft on a far greater scale than ever before.

Mr. Pritchard and the Birmingham Aluminium Casting Co. (1903), Ltd., took out a British Patent (521,089, 1939), the specification of which describes the "preferred alloy" as containing 3% copper, 5% silicon, 0.7% manganese and impurities not exceeding 1.3%. The limits of composition laid down in the original Ministry of Aircraft Production Material Specification D.T.D.424 were:

	Min.	Max.
Copper .. .. .	2.0%	4.0%
Silicon .. .. .	3.0%	6.0%
Manganese .. ..	—	0.7%
Iron .. .. .	—	0.8%
Magnesium .. ..	—	0.15%
Nickel .. .. .	—	0.35%
Zinc .. .. .	—	0.20%
Titanium .. .. .	—	0.20%

Ultimate tensile strength and elongation were to be not less than 9 tons/sq. in. and 2% respectively. The current specification B.S.1490-LM-4M shows the following composition changes:

	Min.	Max.
Copper .. .. .	2.0%	4.0%
Silicon .. .. .	4.0%	6.0%
Manganese .. ..	0.3%	0.7%
Zinc .. .. .	—	0.5%
Tin .. .. .	—	0.05%
Lead .. .. .	—	0.1%

The tensile requirements for sand cast test pieces are the same, but a minimum of 10.0 tons/sq. in. U.T.S. is required for chill cast test pieces, the minimum elongation being 2% in both cases.

The specification has always been sufficiently wide to permit the manufacture of D.T.D.424 from Duralumin-type and other scrap and was, therefore, admirably adapted to the conditions prevailing during the 1939-45 war, especially in the early years when the shortage of primary aluminium was most severe. Castings of good quality were in great demand and could be made in D.T.D.424 from material available, though not without difficulty until manufacturing techniques had been worked out in detail. The British Non-Ferrous Metals Research Association attacked various problems arising in connection with degassing, hot-tearing, iron segregation, the effect of magnesium and other impurities, etc.<sup>4,5,6</sup> The present paper describes further investigations relating to the manufacture of D.T.D.424 from swarf or from skimmings, and the influence of certain impurities, fluxing, gas content, grain size and heat-treatment. The work throughout had the practical aim of ascertaining the influence of these variables on casting characteristics and mechanical properties, and of indicating how, and to what extent, they should be controlled to promote ease of manufacture and the production of serviceable castings.

The work was of an *ad hoc* type, carried out to answer specific and urgent questions. There is, therefore, little attempt to study the fundamental factors involved, but it is felt, nevertheless, that the factual information obtained is worth putting on record.

#### D.T.D.424 MADE FROM SWARF

Some tests on the casting characteristics and mechanical properties of alloys to D.T.D.424 specification, made from swarf, had previously been made, but the interpretation of the results was difficult owing to the variable

<sup>\*</sup> B.N.F.M.R.A. Report R.R.A.904P, based on reports R.R.A.589, 501, 626, 662, 665.

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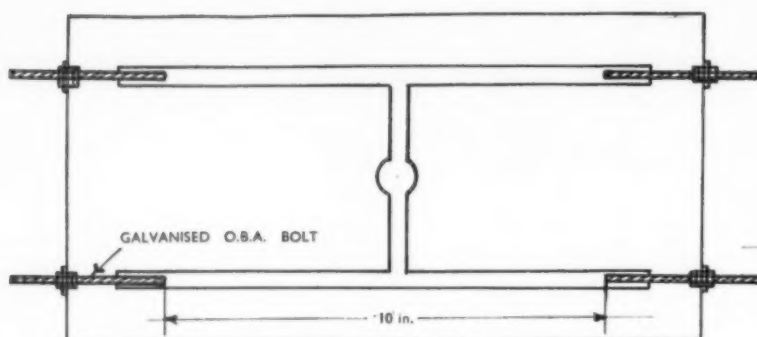


Fig. 1.—The hot-tearing test.

composition of the swarf used; it appeared, however, that there were no significant differences in these respects between (1) alloys prepared from untreated swarf, (2) alloys prepared from ingot metal obtained from specially prepared swarf, and (3) alloys prepared from virgin materials. A further, more comprehensive, series of tests on the casting characteristics of alloys prepared from untreated Duralumin swarf, and on alloys of similar composition prepared from virgin materials was therefore made, together with some tests on material deliberately machined to swarf. Tests on the effects of additions of zinc, tin and lead as impurities were also carried out. The results of all these tests are described in the first part of this paper.

#### Experimental Details

For the main series of tests 30–35 lb. melts were prepared in a gas injector furnace. The swarf was melted in two ways, designated A and B. In method A, designed to be as bad as possible, the crucible was filled with swarf and heated until this had run down, being then refilled and reheated and so on. An oxidising flame was used, although it is doubtful whether an oxidising atmosphere was obtained inside the crucible, as the swarf was oily, the oil burning for much of the time during melting. Between additions of swarf, the metal was allowed to reach a temperature of about 900° C. When sufficient metal had been obtained, the large amount of accumulated oxide was removed and the required quantities of 50/50 aluminium-silicon hardener and of commercial aluminium were added to correct the composition. To degas the metal, about 2% by weight of a flux (two parts of sodium chloride and one part of sodium fluoride) was paddled on to the surface for about two minutes, and the metal was ingoted.

In Method B a small amount of ingot metal, made previously from swarf, was first melted and the remainder of the swarf added in small amounts pressed under the surface of the molten metal. The temperature of the metal was not allowed to rise above 800° C. and a reducing flame was used. After sufficient metal had been melted, the same procedure as for method A was used.

No flux was used during melting by either method, other than that used in the subsequent degassing; the yield of metal was about 80% in all melts, with a slightly higher average loss with method A.

For the melts of virgin material, commercial aluminium was first melted, the necessary hardeners added, and the melt heated to 800° C. to effect complete

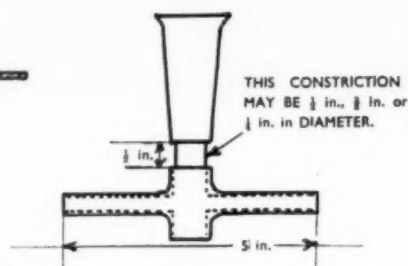


Fig. 2.—Pressure tightness test disc.

solution of the hardeners. After degassing the metal was ingoted.

#### Description of Test Castings

**Hot-tearing test.**—The test casting, shown in Fig. 1, consists of two parallel half-inch diameter bars whose contraction is not hindered by changes in section in the mould cavity. Threaded bolts fitted into the mould form chill inserts in each end of the bars and the bolts are secured to a rigid steel moulding flask. By suitable adjustment of the nuts securing the bolts to the flask, the test bars may be totally restrained, or may be permitted to shrink to some extent before the restraint comes into action. The total linear contraction of the alloys was assumed to be 1.5%, and the nuts were adjusted to permit part or none of this contraction to take place freely. This casting was poured at 740° C.

The test was not very severe and in later work it was found necessary to devise a more severe form of test for distinguishing between alloys which had a high resistance to hot tearing.<sup>4</sup> The observations in the present work, therefore, are governed by the relative mildness of the particular test used.

**Disc test casting.**—This was used for testing for susceptibility to shrinkage defects (surface shrinks and cracks, internal porosity and resultant lack of pressure tightness), and is shown in Fig. 2. The severity of the test can be varied by altering the diameter of the constricted portion of the feeders. The discs were examined for cracks and sinks which tend to occur at the roots of the bosses. Pressure tightness was determined by applying air at a pressure of 200 lb./sq. in. to one side of the disc, the other side being covered with paraffin to facilitate the detection of leakage. When a disc showed no leakage, or only very slight leakage, as-cast, the surface was machined off as shown by the dotted lines in Fig. 2, and the test repeated.

**Uprun bar test for effects of internal shrinkage porosity on mechanical strength.**—The casting shown in Fig. 3 was poured at 740° C. With this design, shrinkage porosity tends to concentrate in the thickest parts of the bars. The amount of porosity was determined by density measurements: the maximum density of the particular alloy was assumed to be that of a slice cut from a directionally solidified block, the slice being taken a little away from the chilled face of the block to avoid possible segregation effects. Four tensile test specimens were machined from the bars after the density measurements had been made and the results were averaged. The effect of internal porosity on tensile strength is expressed by quoting the strengths of specimens machined from these bars as percentages of the strengths of D.T.D. bars poured from the same melt.



A TUNDISH WAS USED TO  
CONTROL THE POURING RATE

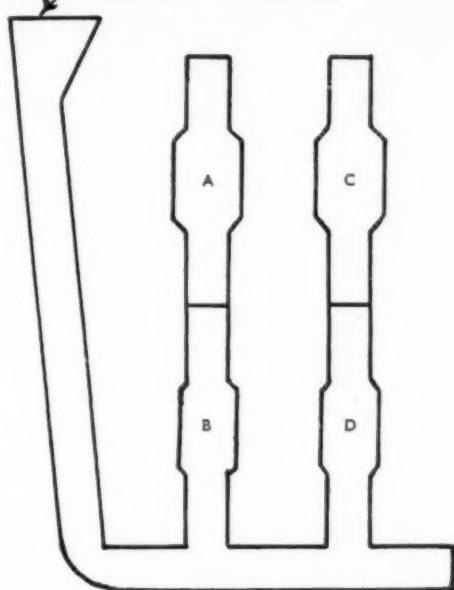


Fig. 3.—Uprun bars (inadequately fed)—approximately  $\frac{1}{4}$  scale.

*D.T.D. standard test bars.*—Four were cast from each melt.

#### Details of the Melts

Six melts of swarf were made in all. The swarf as received contained 4.4% of copper, so that some dilution was necessary to produce representative compositions. The details of the amount of dilution carried out and the method used for each melt are given in Table I, which also gives the analyses of these alloys and of those prepared from virgin materials. In each case, one of the alloys made up from virgin materials was free from magnesium, and approximately 0.2% magnesium was added to the other.

TABLE I.—ANALYSES OF MELTS MADE FROM SWARF

Melt No.	Dilution and Method of Melting	Cu %	Fe %	Si %	Mn %	Mg %	
1	25% A	3.21	0.42	5.78	0.39	0.15	Ni, Zn, Sn, Pb, were not detected spectroscopically
7	25% A	3.09	0.44	5.78	0.43	0.33	
2	25% B	3.25	0.42	5.98	0.41	0.36	
8	25% B	3.18	0.41	5.30	0.44	0.34	
3	Virgin (1)	3.04	0.40	5.90	0.33	Nil	
21	" (3)	3.03	0.54	5.69	0.32	0.25	
4	50% A	2.25	0.37	5.62	0.27	0.17	
5	50% B	2.16	0.41	5.74	0.24	0.15	
6	Virgin (2)	2.14	0.42	5.82	0.19	Nil	
22	" (4)	2.10	0.43	5.81	0.17	0.18	

#### Results

*Hot-tearing test.*—In melts 1–6, each of the bars of the casting was allowed a small contraction (for one bar 10%, and for the other 25%) before the restraining effect of the bolts came into action. None of these bars tore or showed any sign of cracking. In melts 7, 8, 21 and 22, 90% restraint and full restraint were used on the two bars, still with no cracking. Metal of this composition therefore withstands this test, despite the fact that it was made originally from swarf which was not remelted under ideal conditions.

*Disc test casting.*—Three discs were cast from each melt, all at 700° C., and with  $\frac{1}{8}$ ,  $\frac{3}{8}$  and  $\frac{1}{4}$  in. constrictions. With the smaller constrictions, the alloys prepared from swarf and those prepared from virgin materials (with magnesium additions) tended to fine cracks rather than to the sinks found with the virgin materials free from magnesium, but otherwise there was little difference in appearance or pressure tightness between the swarf alloys and those prepared from virgin aluminium.

*Uprun bar test.*—Only small differences were found in the mechanical properties of uprun bars prepared in the ways described, and these were probably due to the variation in magnesium content rather than in the method of preparation.

*Tensile properties of D.T.D. bars.*—The D.T.D. test bars showed little variation in tensile strength, whether prepared from swarf or virgin material, by method A or B, an average figure being 10.4 tons/sq. in. U.T.S. Elongation was somewhat higher in the alloys made from virgin materials, especially those with no deliberate magnesium additions, averaging 2.4% against 1.4% for the alloys made from swarf.

#### Tests on Material Deliberately Made into Swarf

Two melts of a typical D.T.D.424 composition were made from virgin materials and cast into blocks. Half the blocks from each melt were reduced to swarf by a mechanical shaper, oil being used as a lubricant. The two lots of swarf were then remelted together, using method A. The loss of metal by oxidation was somewhat less than in the earlier tests, the swarf being in thicker pieces. The metal was ingoted; analyses made to determine the change of composition gave the following results:

	Blocks	Ingoted Swarf
Copper .. .. .	2.87%	2.83%
Iron .. .. .	0.63%	0.63%
Silicon .. .. .	5.23%	5.06%
Magnesium .. ..	0.10%	0.08%

Melts were then made of this ingoted swarf and of the remaining blocks, 0.2% silicon and 0.02% magnesium being added to the metal prepared from swarf to bring both melts to the same composition. The metal also contained 0.4% manganese, and 0.1% each of nickel and zinc. The same castings as before were made from each melt, and the results in general conformed with those already reported, showing no significant differences between the two materials in either casting characteristics or mechanical properties.

#### D.T.D.424 MADE MAINLY FROM SKIMMINGS

In consequence of a report that the presence in the charge of as little as 5% of metal recovered from skimmings resulted in bad properties in the castings subsequently made from the melt, a short series of tests, similar to those reported above, was made using concentrate prepared from D.T.D.424 skimmings. This concentrate lost half its weight on remelting under common salt and then contained 1.12% iron; it was diluted with half its weight of commercial aluminium with small additions of copper and silicon, to bring the alloy to a representative D.T.D.424 composition. Analysis of the test castings gave copper 3.00%, iron 0.82%, silicon 5.74%, manganese 0.33%, magnesium 0.05%, zinc 0.33%. Castings of similar composition, cast from remelted castings made from virgin materials,

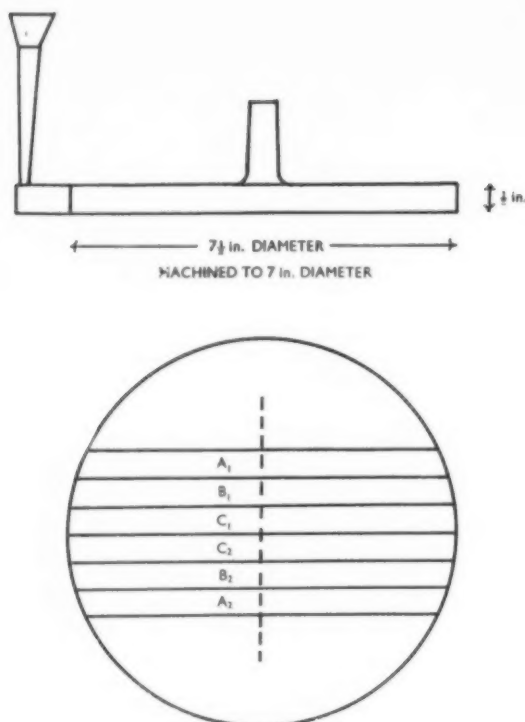


Fig. 4a (top).—7 in. disc casting.

Fig. 4b (bottom).—Arrangement of bars cut from 7 in. disc.

were put through the same tests for comparison. Both melts were degassed before casting and were poured at 740° C.

Practically identical results were given by the two alloys in all the tests.

#### Effect of Small Amounts of Zinc, Tin and Lead

The addition of 0.6% zinc to D.T.D.424 was shown earlier to have no effect on tensile properties or on casting characteristics, as assessed by the disc casting test. It was later suggested, however, that this amount of zinc might be detrimental in the presence of certain other impurities, particularly tin and lead. Tests were then made to find out whether this was so, and to check the effect of zinc only by use of the hot-tearing test. From each melt D.T.D. bars, two disc castings and a hot-tear test casting were made.

The basis alloys used for these tests were: Series I remelted castings from melts 4, 7 and 8 (see Table I); Series II remelted castings from melt 6 (Table I) and from other virgin melts; Series III scrap D.T.D.424 of two compositions, both of which already contained small amounts of zinc, further additions of zinc (0.5% and 0.4%) being made, giving final zinc contents of 0.69% and 0.65%. These last castings were made from separate 5 lb. melts, the only differences in treatment being the addition of zinc to some of the melts. The whole of the metal in Series I and II was first melted and ingoted to bring it to one composition. Metal for I originated as swarf and had the following composition:

2.78% Cu; 0.42% Fe; 5.2% Si; 0.38% Mn;  
0.22% Mg

The metal used for Series II originated as virgin aluminium and small additions of hardeners, the resulting composition being:

2.58% Cu; 0.71% Fe; 5.8% Si; 0.37% Mn;  
0.14% Mg; 0.10% Ti.

The results obtained after additions of tin (0.2%) lead (0.2%) and zinc are summarised below.

(i) Ultimate tensile strength and elongation were not affected by the additions.

(ii) Zinc additions had little effect on the disc castings, but tin and lead increased the tendency to shrinkage cracking. Addition of zinc to alloys already containing tin and lead had little further effect.

(iii) Results of the hot-tearing tests showed that the effect of zinc, if any, was very small, and possibly within the limits of experimental error. Tin and lead additions also had little effect, any tendency observed being to promote tearing. The presence of tin, lead and zinc together had no greater effect.

## Part II

### Effects of Grain Size and Gas Contents

The comparative trials described in this section were carried out on two batches of D.T.D.424 alloy, reported by an aluminium foundry as "good" and "bad" respectively, with the object of ascertaining the causes and effects of the differences between the two batches. Their analyses are given in Table II.

Spectrographic analysis indicated the absence or presence only in traces, of other elements, and no differences of any significance were found.

#### Methods of Test

**Gas content.**—Equal weights (400 g.) of the two batches were placed in two clean fireclay pots standing side by side in the same electric resistance furnace in which they had previously been held for 2 hours at 800° C. The samples melted down at very nearly equal rates. At 700° C. a small sample (about 40 g.) was removed and allowed to freeze under a pressure of 40 mm. of mercury. The samples thus frozen under low pressure were sectioned and examined visually to assess the gas content of the samples.

**Casting characteristics.** The following castings were run in the two batches of alloy:

**D.T.D. standard test bars.**—Two were poured from each batch.

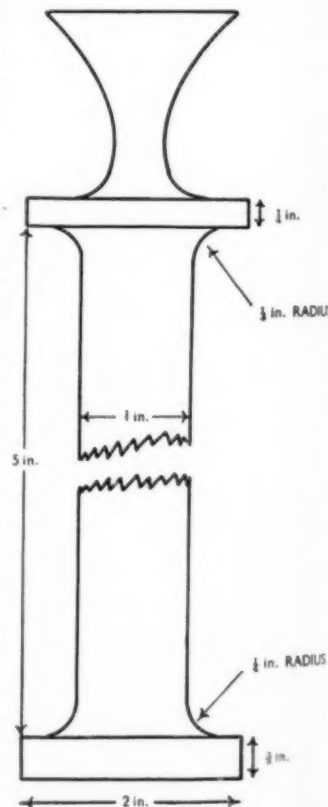


Fig. 5.—Hot-tear test casting.

TABLE II.—ANALYSES (%) OF "GOOD" AND "BAD" BATCHES OF D.T.D.424

	Ca	Si	Fe	Mn	Ni	Ti	Zn	Pb	Sn	Mg
LJK "Good"	3.1	3.1	0.50	0.36	0.13	0.16	0.10	0.07	0.02	0.21
LJL "Bad"	3.4	4.95	0.54	0.50	0.38	0.04	0.30	0.12	0.06	0.27

7 in. diameter discs, illustrated in Fig. 4 (a). Six rectangular bars for subsequent machining into tensile test pieces were cut from the disc as shown in Fig. 4 (b). Before testing, the porosity was determined by density measurements.

**Chill blocks.**—A block 2 in. diameter and 3½ in. long, cast in a sand collar on a copper chill, froze almost unidirectionally; a slice taken from near the bottom was used as a standard of sound material for density determinations.

**Pressure-tightness discs.**—Pressure-tightness discs as described in Part I, with ¾ in. and ¼ in. dia. constrictions in the ingates, were tested for leakage under pressure, as-cast and after machining off the surface skin.

**Hot-tearing tests.**—Castings as shown in Fig. 5 were run in a copper die described previously in detail,<sup>4</sup> the diameter of shank being 1 in.

**Melting procedure.**—10 lb. melts, made in a small gas fired injector furnace, were poured at 700° C. without any fluxing or other degassing treatment.

**Grain size.**—Samples cut from just below the head of a D.T.D. bar were macro-etched with a mixture of nitric and hydrofluoric acids.

### Results

The gas content of the "good" material was found to be much higher than that of the "bad" material.

The grain size of the "good" material was reasonably fine, the grains being equiaxial. The "bad" material showed a much coarser macrostructure with a tendency towards columnar growth.

The results of the mechanical tests are given in Table III.

TABLE III.—RESULTS OF TESTS ON "GOOD" AND "BAD" MATERIALS

Property	LJK "Good"	LJL "Bad"	Remarks
0.1% proof stress, tons/sq.in. . . . .	5.5	3.6	D.T.D. bars
U.T.S. tons/sq.in. . . .	10.9	9.5	" "
Elongation % on 4√A°	2.5	2	" "
U.T.S. tons/sq.in.° . .	8.6	7.0	Cut from 7 in. disc A bars
	7.6	5.3	" " " B "
	5.7	4.7	" " " C "
Elongation % on 4√A°	2	1.5	" " " A "
	1.5	1.5	" " " B "
	1	1.5	" " " C "
% Voids . . . . .	2.8	3.2	Bars from 7 in. disc A bars
	3.1	3.5	" " " B "
	3.1	3.8	" " " C "
% D.T.D. Strength . .	79	71	" " " A "
	70	54	" " " B "
	82	48	" " " C "

° Each figure quoted is mean result of two bars.

The pressure tightness discs showed very little difference between the two batches. Externally all discs appeared perfect and, although the ¼ in. diameter constriction disc in batch LJL leaked slightly under pressure, it cannot be said that this result on one disc has great significance.

In the hot-tearing tests the "bad" material tore, whereas the "good" material did not.

### Discussion

Both alloys conform in chemical composition to the D.T.D.424 specification except that the magnesium content of both batches is above the limit. The marked difference in titanium content ("Good" 0.16%, "Bad" 0.04%) is reflected in the very different grain sizes of the two batches.

The two batches also differed considerably in gas content, the "bad" batch being almost gas-free.

The mechanical properties of D.T.D. bars cast from the two batches conform to the D.T.D.424 specification requirements except that the "bad" batch did not reach the 0.1% proof stress given for information. The "good" batch (LJK) had distinctly better mechanical properties.

The 7 in. disc casting gives six inadequately fed bars. Density measurements showed that these bars contained considerable porosity (2.8-3.8%), the LJL ("bad") bars being more porous than the LJK bars. The mechanical properties of these bars are given in Table III and are also expressed as a percentage of the strength of the D.T.D. bars cast from the same melt; LJK ("good") gives in each category a higher percentage D.T.D. strength than LJL.

Tests carried out to determine the distribution of porosity along the length of the 7 in. bars showed that, in each bar, there was a distinct concentration of porosity towards the centre of the length, the concentration towards the centre being stronger in the "bad" batch than in the "good" batch. Work by the Association on the casting of bronzes has shown that the concentration of porosity at a heat centre may be very greatly lessened by the presence of dissolved gases in the melt, and the higher gas content of the "good" material is probably responsible for this effect.

Previous work<sup>4,6</sup> has shown that important factors governing the casting behaviour and mechanical properties of aluminium alloys are constitution, in particular, the proportion of eutectic in the alloy (largely determined by the copper and silicon contents in the case of D.T.D.424), and grain size. For example, coarse-grained material is more prone to tearing than fine-grained, and the superiority of the "good" material over the "bad" in this test is in accordance with this general finding. Since the two batches do not differ significantly except in regard to titanium, which powerfully affects the grain size, and gas content, it may be concluded that these are the factors causing the differences in behaviour.

### Part III

#### The Effect of Heat Treatment

As early as 1928, Gwyer, Phillips and Mann,<sup>7</sup> working on a chill-cast alloy containing 3.79% copper, 3.97% silicon and 0.26% iron, showed that solution treatment followed by precipitation treatment produced a great increase in mechanical properties of the alloy. They obtained a tensile strength of 17-19 tons/sq. in. and 8-10% elongation after 24 hours solution treatment at 520° C. followed by quenching and precipitation for 48 hours at 150° C.

Archer and Jeffries (In Brit. Pat. Spec. 173, 746) described the heat-treatment of chill-cast alloys

<sup>7</sup> Gwyer, Phillips and Mann, *J. Inst. Metals*, 1928, **40**, 347.

TABLE IV.—COMPOSITIONS OF ALLOYS HEAT-TREATED

Mark	Cu%	Si%	Fe%	Mg%	Mn%	Ni%	Ti%	Zn%	Sn%	Pb%
KGN	2.20	5.4	0.83	0.12	0.41	0.1	0.12	0.1	trace	trace
KKP	2.82	5.21	0.88	0.02	0.37	0.15	0.15	0.4	0.03	0.17
KWZ	2.83	5.0	0.73	0.23	0.29	0.20	0.21	0.35	0.05	0.05
KRP	2.35	4.1	0.08	—	—	—	0.10	—	—	—
KRM	2.44	4.53	0.30	—	—	—	0.19	—	—	—
LJB	2.54	9.6	0.16	—	—	—	0.01	—	—	—
LJC	2.39	4.4	0.05	—	—	—	0.01	—	—	—
LNJ	2.56	5.22	0.12	—	—	—	0.06	—	—	—
LNW	2.51	4.7	—	—	—	—	0.06	—	—	—
LNI	2.51	5.02	0.16	—	0.25	—	0.06	—	—	—
LSJ	2.58	4.74	0.16	—	—	—	0.10	—	—	Cu 0.26
LMG	2.50	4.6	0.15	—	—	—	0.09	—	—	—
LMH	5.14	4.9	0.15	—	—	—	0.09	—	—	—

containing 2-5% copper, 3-15% silicon at slightly below 520° C., followed by ageing at 100-150° C. Tensile strengths of 18-20 tons/sq. in. were obtained.

In a few tests on sand-cast test bars of an aluminium-copper-silicon alloy, made and tested in the Association's laboratories, tensile strengths of 20-21 tons/sq. in. with 0.5% elongation were obtained after solution-treatment for 16 hours at 500° C., quenching and precipitation-treatment for 16 hours at 160° C. The approximate composition of this alloy was 4% Cu, 0.4% Fe, 2.6% Si, 0.5% Mn, 0.5% Mg, 0.1% Ti.

A further series of tests was then carried out on various alloys conforming to, or only just outside, the composition limits set by specification D.T.D.424, to determine how these alloys would respond to heat treatment.

#### Experimental Procedure

Melts were prepared from virgin metals, or from scrap, in a gas-fired injector furnace, and were degassed using a flux containing two parts of sodium chloride and one part of sodium fluoride. D.T.D. test bars were poured in green-sand moulds at 700° C. In heat treatment, the temperature was controlled to  $\pm 2^\circ$  C. during solution treatment and to within 1° C. during precipitation treatment.

TABLE V.—MECHANICAL PROPERTIES OF AS-CAST AND HEAT-TREATED D.T.D. TEST BARS (Mean of two results except where marked\*)

Mark and Composition	Condition	0.1% P.S., tons/sq.in.	U.T.S., tons/sq.in.	Elong. % on 4√A
2.44% Cu, 4.53% Si, 0.30% Fe (virgin material)	As cast	—	9.5	3
	Solution-treated 14 hrs. at 525° C.	—	11.8	4
	Solution-treated as above: 3½ hrs. precipitation-treatment at 160° C.	—	13.4	6
	Solution-treated as above: 24 hrs. precipitation-treatment at 160° C.	—	14.1	3
2.35% Cu, 4.1% Si, 0.08% Fe (virgin material)	As cast	—	11.6	9
	Solution-treated 14 hrs. at 527° C.: 18 hrs. precipitation-treatment at 160° C.	—	15.1	9
2.54% Cu, 9.6% Si, 0.16% Fe (virgin material)	As cast	3.8	10.6	6
	Solution-treated 4½ hrs. at 520° C.: 19 hrs. precipitation-treatment at 160° C.	6.5	14.1	6
2.39% Cu, 4.4% Si, 0.05% Fe (virgin material)	As cast	3.2	10.9	9.5
	Solution-treated 4½ hrs. at 520° C.: 19 hrs. precipitation-treatment at 160° C.	5.8	14.8	9
2.51% Cu, 5.02% Si, 0.16% Fe, 0.25% Mn (virgin material)	As cast	4.2	11.0	5
	Solution-treated 6 hrs. at 518° C.	5.5	13.8	6.5
	Solution-treated as above: 15 hrs. precipitation-treatment at 160° C.	6.7	14.1	5
2.58% Cu, 4.74% Si, 0.16% Fe, 0.26% Co (virgin material)	As cast	4.0	8.8	4
	Solution-treated 6 hrs. at 518° C.	4.9	14.1	3.5
	Solution-treated as above: 15 hrs. precipitation-treatment at 160° C.	(not reached before U.T.S.)	14.7	1
2.50% Cu, 4.6% Si, 0.15% Fe (virgin material)	As cast	3.9	10.6	4.5
	Solution-treated 6 hrs. at 520° C.	7.0	14.3	5
	Solution-treated as above: 13 hrs. precipitation-treatment at 160° C.	9.3	16.0	3.5
5.14% Cu, 4.9% Si, 0.15% Fe (virgin material)	As cast	4.1	10.6	3
	Solution-treated 6 hrs. at 520° C.	9.7	14.3	2
	Solution-treated as above: 13 hrs. precipitation treatment at 160° C.	13.3	16.2	1
2.51% Cu, 4.7% Si, 0.03% Fe (virgin material)	As cast	3.8	12.8*	5*
	Solution-treated 6 hrs. at 520° C.: 13 hrs. precipitation-treatment at 160° C.	7.2	15.7	9
2.56% Cu, 5.22% Si, 0.12% Fe (virgin material)	As cast	3.3	11.0	6.5
	Solution-treated 6 hrs. at 520° C.	5.2	12.1	5
	Solution-treated as above: 20 hrs. precipitation-treatment at 160° C.	9.7	12.6	5

#### Materials Used

With three exceptions (KGN, KKP, KWZ) the alloys were made from virgin materials and were essentially free from the impurities magnesium, nickel, manganese, zinc, tin and lead, none of which is likely to exceed 0.01%.

Three alloys (KGN, KKP, KWZ) were secondary materials of similar composition to commercial material. Analyses of the alloys are given in Table IV.

#### Results and Discussion

The mechanical properties of the alloys in the as-cast, solution-treated, and solution-treated and precipitation-treated conditions are given in Table V. The alloy KWZ was examined to determine the effect of the duration of heat treatment time, and the results are given in Table VI.

#### Sand Cast Secondary Alloys

##### The Effect of Duration of Heat Treatment

In exploratory tests on the commercial alloys KGN and KKP, heat-treatments of unusually long duration were given; the results showed that strengths of the order of those obtained with other heat-treated aluminium casting alloys (20 tons/sq. in. U.T.S.) could be obtained with secondary D.T.D.424 alloy of ordinary commercial composition. No difference due to the varying magnesium content (0.02-0.12%) was observed although, in the as-cast state, variations of magnesium content above and below about 0.05% had previously been found to cause wide differences in the room temperature age-hardening behaviour of alloys of this type.

Tests on the effect of heat-treatments of varying duration were made on the secondary alloy KWZ. A higher magnesium content (0.23%) was used because of



TABLE VI.—EFFECT OF VARIOUS TIMES OF HEAT-TREATMENT ON KWZ ALLOY†  
(Mean of two results except where marked\*)

Mark and Solution Treatment	Precipitation Treatment	0.1% P.S.* tons/sq.in.	U.T.S. tons/sq.in.	Elong. on 4√A
A. 2 hrs. at 520° C.	6 hrs. at 164° C.	13.1	17.2	1.5
	12 hrs. at 166° C.	—	19.0	0.5
	18 hrs. at 166° C.	—	19.1	1
B. 4 hrs. at 520° C.	6 hrs. at 164° C.	—	17.4	1
	12 hrs. at 166° C.	18.4	19.8	0.5
	18 hrs. at 166° C.	—	19.5	1
C. 9 hrs. at 520° C.	6 hrs. at 164° C.	—	18.2	1
	12 hrs. at 166° C.	—	20.4	0.5
	18 hrs. at 166° C.	18.5	20.0	1

†2.83% Cu, 5.0% Si, 0.23% Mg (secondary material)

a suggestion that control of magnesium during remelting is easier at percentages of this order. With 9 hours solution-treatment, U.T.S. 20.4 tons/sq. in. was reached after 12 hours precipitation, whereas 4 hours solution-treatment and 12 hours precipitation treatment gave U.T.S. 19.5 tons/sq. in. and an elongation of 0.5% on 4√A. The 0.1% proof stress, was 18.4 tons/sq. in., which is as high as that of any of the heat-treatable aluminium casting alloys in current use. With more than 12 hours precipitation-treatment there is a noticeable over-ageing effect (Fig. 6).

Tests have been made on the effect of internal shrinkage porosity on heat-treated secondary D.T.D.424 alloy using the methods described in Part I, and the strength retained in sand cast poorly fed test bars is the same high proportion of the fully fed test bar strength as is obtained in as-cast material of the same composition.

#### Chill Cast Secondary Alloys

A small commercial die casting in D.T.D.424 alloy, as cast, gave U.T.S. 13.6 tons/sq. in. and elongation 1%. When solution-treated 6 hours at 522° C. and precipitation-treated 12 hours at 160° C., these figures were raised to 24.4 tons/sq. in. and 2%.

#### Sand Cast Virgin Alloys The Effect of Composition

The as-cast purer alloys made from virgin metals have substantially the same strengths but considerably higher elongations than the relatively impure secondary alloys described above. In the solution-treated condition the virgin alloys had moderately high strengths and elongations similar to those obtained from the less pure secondary material. The purer virgin alloys are much less responsive to precipitation treatment than the secondary material and, consequently, the strengths obtained in the fully heat-treated condition are considerably lower, but the elongations are correspondingly higher.

Virgin alloys based on the composition 5% silicon, 2.5% copper, were made up with varying iron contents to determine the possibility of obtaining a useful combination of strength and ductility with good casting characteristics. The alloy LNY, containing 5.22% Si, 2.56% Cu and 0.12% Fe, gave U.T.S. 15.6 tons/sq. in., 0.1% P.S. 9.7 tons/sq. in. and elongation 5% on 4√A, in the as-cast condition.

The ductility of alloys of this type is markedly affected by their iron content (Table V) and Fig. 7 shows the elongation in the fully heat-treated condition plotted against the iron content. Between 0.06% and 0.12% Fe the fall in ductility is rapid, but beyond 0.12% the reduction is more gradual. Silicon metal as used in industry usually contains about 0.7% iron; conse-

quently to retain a ductility of 5% in the fully heat-treated state it would be necessary to use aluminium containing not more than 0.08% iron (i.e. the relatively high purity commercial grade containing 99.85% aluminium or more). 4% ductility would be retained using aluminium of iron content not more than 0.12%. The effect of increasing iron content on the U.T.S. is relatively slight.

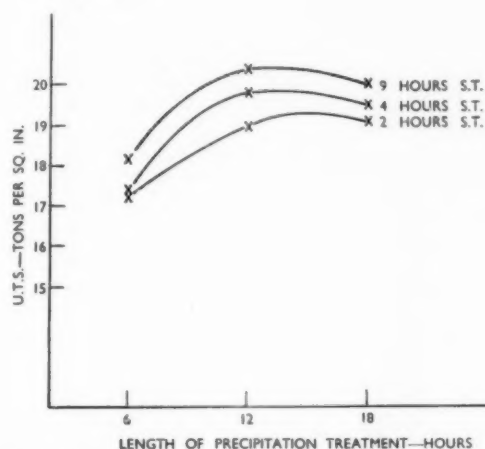


Fig. 6.—Effect of varying times of precipitation treatment at 160° C. on Alloy KWZ, after solution treatments of 2, 4 and 9 hours duration.

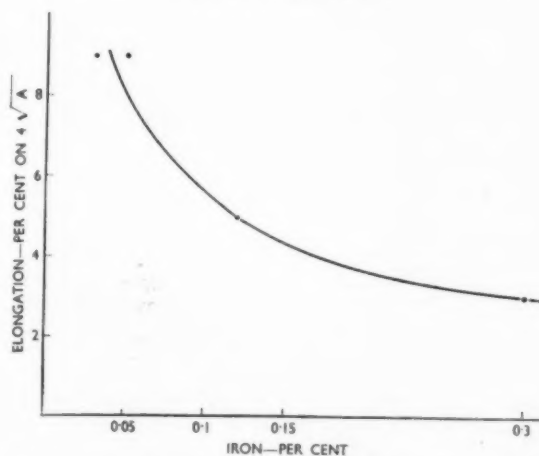


Fig. 7.—The effect of iron content (up to 0.3%) on the elongation of heat-treated sand-cast virgin alloys containing 5% Si and 2.5% Cu.

Two tests were made to determine whether manganese or cobalt would counter the adverse effect of iron on ductility. The addition of 0.2% of manganese had no such effect and a similar addition of cobalt lowered the elongation almost to nil (cf. alloys LNY, LNH, LMJ).

A few tests were made to examine the effects of variations in copper content up to 5% and in silicon up to 10%. With 3.5% copper and 5% silicon the mechanical properties were very similar to those obtained with the alloy containing 2.5% copper and 5% of silicon and having comparable iron content (cf. alloys LMG and LNY), but raising the copper content to 5% (maintaining the silicon unchanged) substantially decreased the ductility and raised the 0.1% proof stress (cf. alloys LMH and LNY). Retaining 2.5% copper and raising the silicon content to 9.6% had only a slight effect, as might be expected; elongation was slightly higher and the 0.1% proof stress appreciably lower than for comparable material of lower silicon content (cf. alloys LJB and LNY).

Where high ultimate tensile strength and proof stress are the major requirements, aluminium-silicon-copper alloys made from secondary metal and containing the normal impurities, including some magnesium, are the most attractive. If ductility in both the as-cast and heat-treated conditions is essential, it is necessary to make up the material from virgin materials of high purity. A copper content of about 2.5% with silicon of 5 or 10% seems to be satisfactory, in either case. Heat treating such material raises the ultimate tensile strength from about 11 tons/sq. in. to about 15 tons/sq. in., and the proof stress from about 4 tons/sq. in. to about 8 tons/sq. in.

The use of the high purity material, in conjunction with double heat treatments, can only be justified in cases where ductility in the finished casting is essential; the increased ductility is only gained at the sacrifice of some strength.

#### General Discussion and Conclusions

The work described in the three parts of this paper was, as stated at the outset, largely *ad hoc* in nature. It was carried out during the war and reported stage-by-stage to the Aluminium Castings Committee of the B.N.F.M.R.A. and should now be viewed against the background of the wide use of D.T.D.424 (now known as LM-4) alloy in both war-time production and in subsequent commercial work of all kinds. The material discussed has proved itself to be highly versatile and has been used in the production of sand, gravity-die and pressure-die castings of all sizes subject to many different kinds of service conditions. Its mechanical properties have been found quite suitable for many general engineering purposes, and other work in the B.N.F.M.R.A. laboratories show that it possesses useful creep properties.

The most significant result coming from this work is considered to be the finding that the origin of the alloy is largely a matter of indifference, provided that the composition and grain size are satisfactory, and that the gas content is suited to the particular work in hand.

It was found for instance that, with the correction of composition, perfectly satisfactory material could be made from machining swarf and foundry residues. This is a result of far-reaching importance, and it is believed that it facilitated the wider use of secondary metal for the production of high-class light alloy castings.

Tests on the casting characteristics of D.T.D.424 alloys made from a variety of sources, both virgin and secondary, show no greater variation than would be expected from the nature of the experimental methods. Complaints have sometimes been made that different batches of this alloy vary in their casting characteristics, and it is satisfactory to note that, in the only such case brought to the notice of the investigators, the difference could be satisfactorily explained in terms of grain size and gas content. This is strictly in accordance with expectation from the work on casting characteristics.

Finally, the extreme versatility of the material has been shown by demonstration that it is amenable to heat-treatment and that ultimate tensile strengths of the order of 19-20 tons/sq. in., for sand castings, and 24 tons/sq. in., for gravity-die castings, can be obtained by a combination of solution and precipitation heat-treatment. It is not claimed that this discovery is entirely original but it was made independently, but at approximately the same time as by other workers.

#### Acknowledgments

The authors are indebted to the Director and Council of The British Non-Ferrous Metals Research Association for permission to publish this paper. Thanks are also due to Dr. H. Moore, who kindly prepared the text for publication, and to Messrs. E. A. G. Liddiard and W. A. Baker for helpful discussion during the course of the work.

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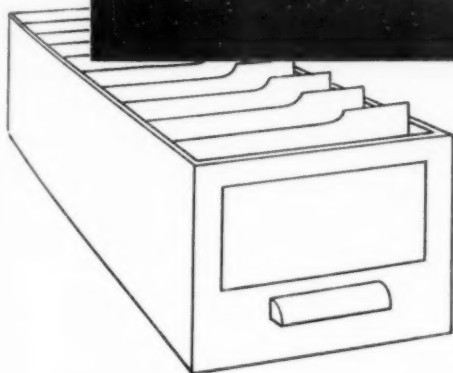
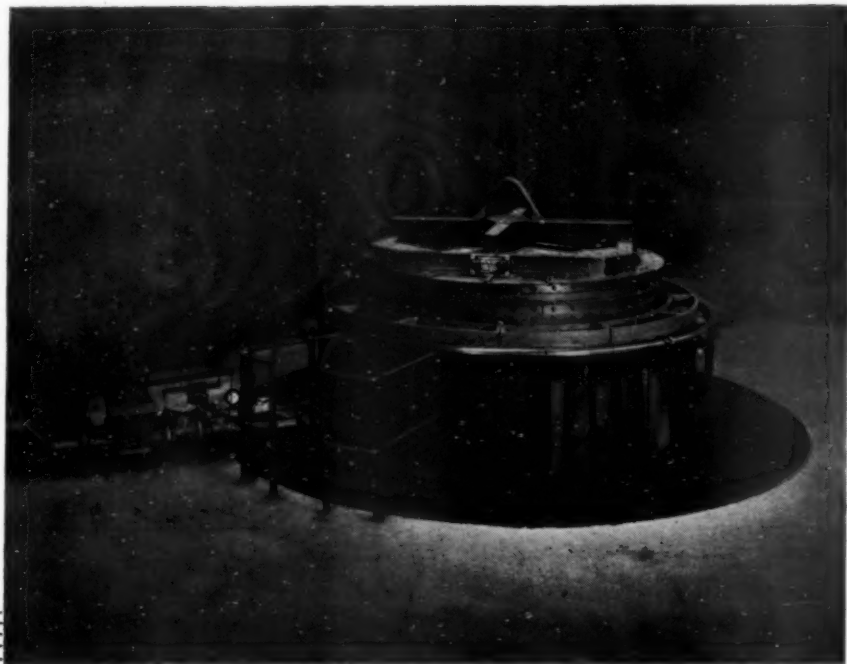
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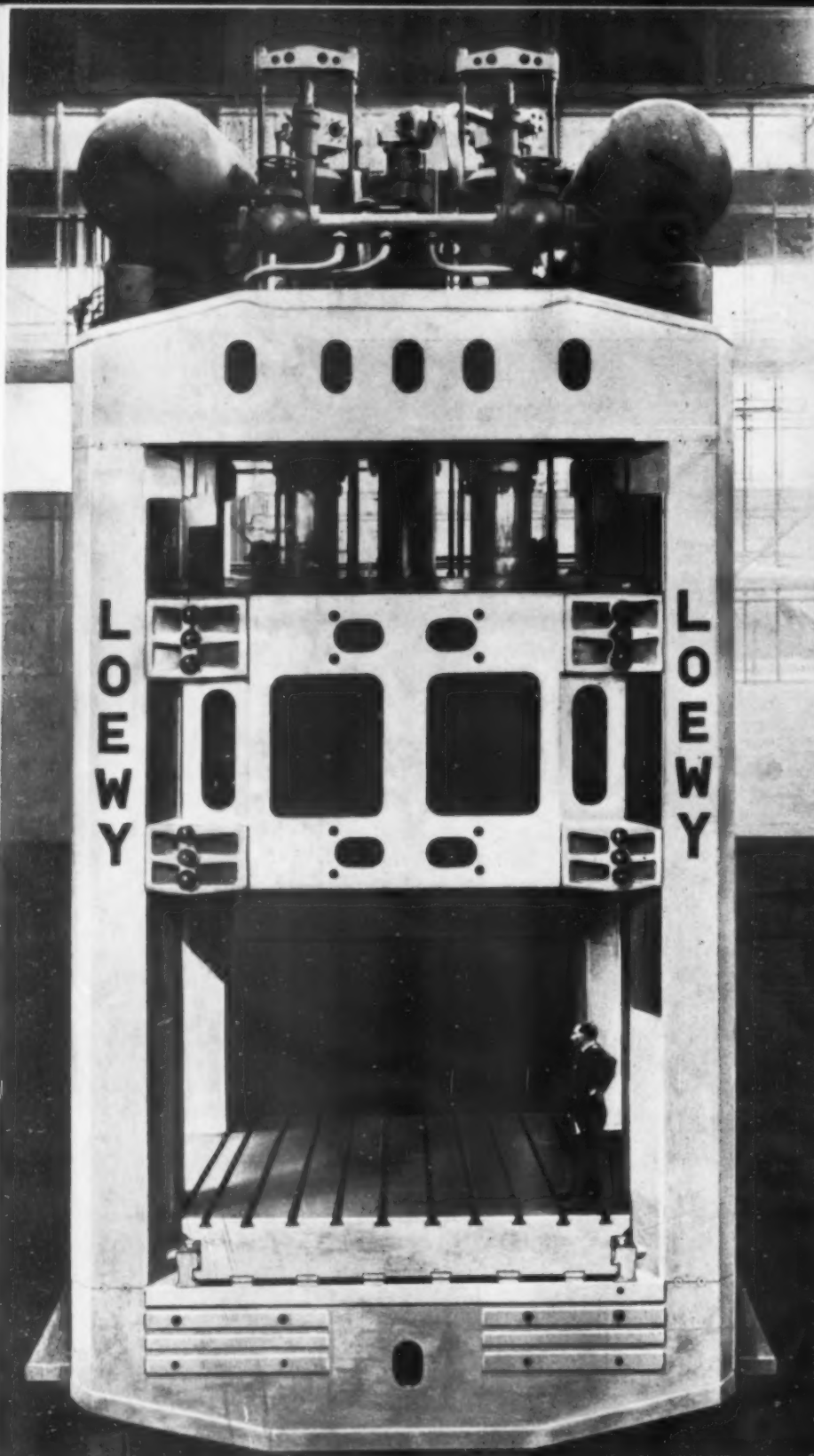
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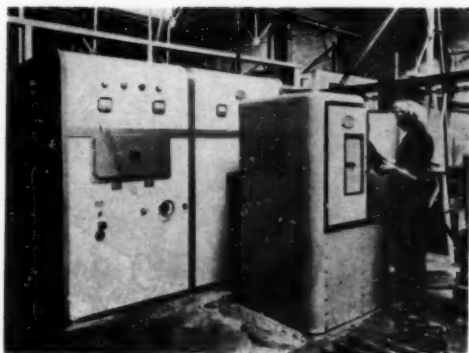


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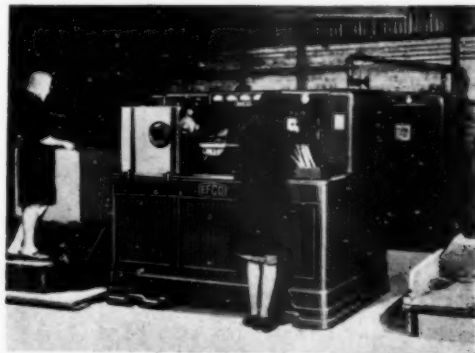
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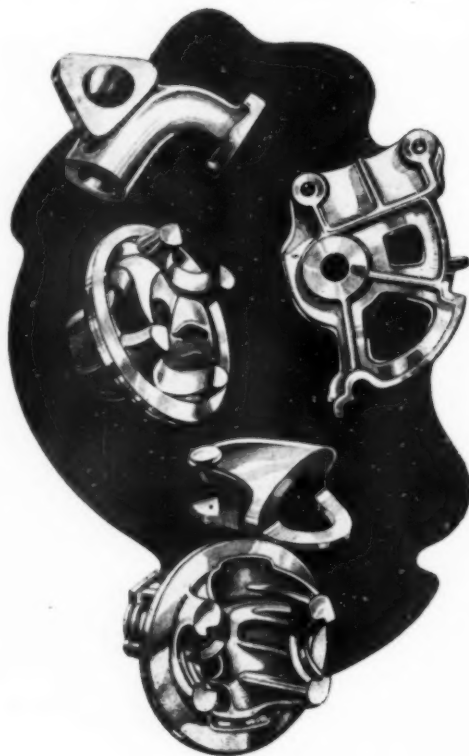


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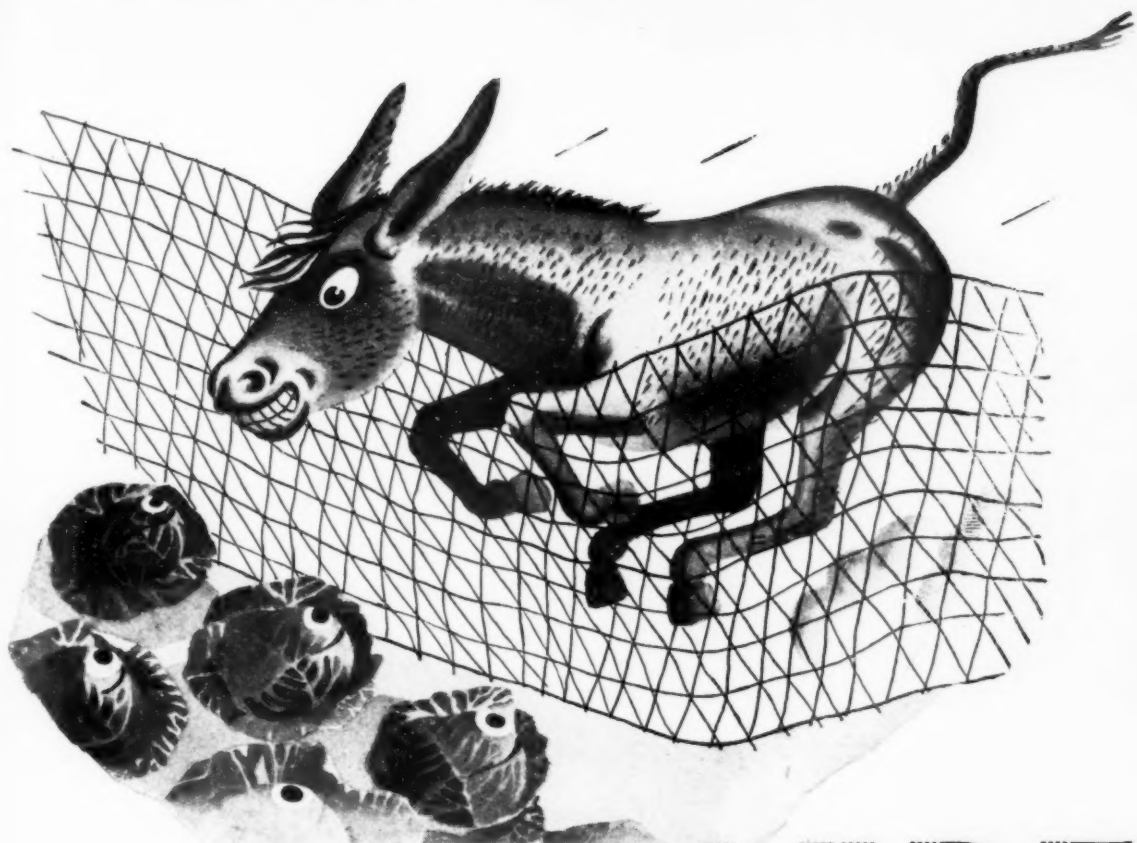
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# The Effect of Isothermal Treatment on the Mechanical Properties of Steel *Continued from page 64*

TABLE I.

Temp. °C.	BREAKING LOAD (tons)			WORK TO FRACTURE		
	Iso- thermal Trans.	Water quench	Oil quench	Iso- thermal Trans.	Water quench	Oil quench
160	0-12	0-05	0-10	0-32	0-03	0-18
180	0-10	0-08	—	0-20	0-07	—
185	0-13	0-08	—	0-10	0-07	—
200	0-17	0-07	0-115	0-62	0-03	0-18
210	0-12	0-07	—	0-10	0-06	—
230	0-20	0-09	—	0-60	0-04	—
250	0-25	0-12	—	0-56	0-05	—
275	0-31	0-07	—	1-04	0-06	—
285	0-31	0-06	—	1-04	0-04	—
300	0-29	0-07	0-13	1-0	0-04	0-20
350	0-25	0-07	0-215	1-5	0-04	0-56
390	0-23	0-15	—	1-9	0-20	—
400	0-24	0-23	0-23	2-0	0-70	0-84
420	0-22	0-23	—	1-7	0-56	—
450	0-23	0-25	—	2-3	1-1	—
475	0-21	0-23	—	2-2	0-70	—
500	0-21	0-22	0-215	1-8	0-72	1-04
550	0-18	0-21	—	2-0	0-80	—
600	0-16	0-18	0-185	1-6	0-90	1-12

TABLE II.

Temperature °C.	VICKERS HARDNESS NUMBER		
	Isothermal Trans.	Water quench	Oil quench
230	700	695	—
250	624	685	661
275	600	661	—
285	590	671	—
300	579	633	610
350	523	587	549
390	496	547	—
400	439	536	507
420	414	511	—
450	406	502	454
475	383	467	—
500	379	470	422
550	309	391	—
600	250	350	315

cracks, present only near the surface and quite distinct from the usual relatively large quenching cracks. Very many of these specimens did not break at the notch, but at one of these cracks. Such fine cracks showed on the fracture as light brown areas. The effect of these cracks seemed to diminish rapidly above about 300° C., fracture then occurring at the notch. This effect is shown in Figs. 1 and 4, as a sharp rise in the curves for the oil- and water-quenched material.

The idea that these cracks are the main cause of brittle fracture in the lower temperature range is supported by the notch-toughness values obtained in a very few cases where fracture occurred at the notch and where no sign of internal cracks was evident. The values obtained under these conditions were much higher than the remainder, being of the same order as the results obtained for the isothermally transformed steel. Only a very few of the specimens behaved in this way, however, and these must be regarded more or less as freaks.

In the course of subsequent work, described later, it was found that in the presence of internal stress, molten solder was liable to make an intergranular attack on steel. Since the specimens quenched in water or oil would be in a state of high internal stress, on immersion in the molten solder used as the tempering medium, penetration would be expected. From the results given above, it will be seen that the embrittlement is reduced when the tempering is carried out at temperatures above 300° C. This, it is suggested, is due to the stress relief being sufficiently rapid at these temperatures to remove

TABLE III.

Trans- formation Temp. °C.	Tempering Temp. °C.	BREAKING LOAD (LBS)		WORK TO FRACTURE		VICKERS HARD- NESS
		Testing Results	Average Value	Testing Results	Average Value	
160	100	0-23 0-28	0-255	0-86 0-95	0-90	496
	150	0-24 0-24	0-24	0-94 0-96	0-95	
	500	0-23 0-22	0-2-5	0-80 1-2	1-0	
	550	0-20 0-22	0-21	1-0 1-2	1-1	
	600	0-18 0-19	0-185	1-3 1-2	1-25	
	400	0-26 0-24	0-25	0-70 1-4	1-05	
	450	0-25 0-21	0-23	1-2 1-0	1-1	
	500	0-21 0-21	0-21	1-1 1-1	1-1	
	550	0-20	0-20	1-0 1-3	1-15	
	600	0-18	0-18	1-2 1-5	1-35	
200	100	0-25 0-25	0-24	0-92 1-2	1-06	507
	150	0-22 0-23	0-225	1-0 1-2	1-1	
	500	0-21 0-22	0-215	1-0 1-0	1-3	
	550	0-19 0-20	0-195	1-0 1-1	1-35	
	600	0-18 0-17	0-175	1-6 1-3	1-45	
	400	0-23 0-23	0-23	1-0 1-4	1-2	
	450	0-23 0-20	0-215	1-2 1-4	1-3	
	500	0-20 0-20	0-20	1-2 1-6	1-4	
	550	0-19 0-19	0-19	1-7 1-4	1-55	
	600	0-17 0-18	0-175	1-6 1-6	1-6	
300	100	0-24 0-20 0-22	0-22	1-6 1-4 1-4	1-45	470
	150	0-21 0-22	0-215	1-6 1-4	1-5	
	500	0-20 0-19	0-195	1-7 1-5	1-6	
	550	0-18 0-20	0-19	1-6 1-7	1-65	
	600	0-17 0-17	0-17	1-6 1-8	1-7	
	450	0-21 0-20	0-205	1-6 1-5	1-55	
	500	0-19 0-21	0-20	1-6 1-7	1-65	
	550	0-19 0-17	0-18	1-9 1-7	1-8	
	600	0-17 0-16	0-165	1-8 1-8	1-8	
	400	0-21 0-20 0-22	0-22	1-6 1-4 1-4	1-45	
350	100	0-21 0-20 0-22	0-22	1-6 1-4 1-4	1-45	470
	150	0-21 0-22	0-215	1-6 1-4	1-5	
	500	0-20 0-19	0-195	1-7 1-5	1-6	
	550	0-18 0-20	0-19	1-6 1-7	1-65	
	600	0-17 0-17	0-17	1-6 1-8	1-7	
	450	0-21 0-20	0-205	1-6 1-5	1-55	
	500	0-19 0-21	0-20	1-6 1-7	1-65	
	550	0-19 0-17	0-18	1-9 1-7	1-8	
	600	0-17 0-16	0-165	1-8 1-8	1-8	
	400	0-21 0-20 0-22	0-22	1-6 1-4 1-4	1-45	
400	100	0-21 0-20 0-22	0-22	1-6 1-4 1-4	1-45	470
	150	0-21 0-22	0-215	1-6 1-4	1-5	
	500	0-20 0-19	0-195	1-7 1-5	1-6	
	550	0-18 0-20	0-19	1-6 1-7	1-65	
	600	0-17 0-17	0-17	1-6 1-8	1-7	
	450	0-21 0-20	0-205	1-6 1-5	1-55	
	500	0-19 0-21	0-20	1-6 1-7	1-65	
	550	0-19 0-17	0-18	1-9 1-7	1-8	
	600	0-17 0-16	0-165	1-8 1-8	1-8	
	400	0-21 0-20 0-22	0-22	1-6 1-4 1-4	1-45	

the main cause of the attack before damage is caused.

The complete absence of penetration in isothermally transformed steel, indicates that the internal stresses set up are too small to have any serious effect.

On these grounds, however, the low notch-bend values obtained in tests on specimens quenched and then tempered below, say, 350° C. must be considered suspect.

#### NOTE ON THE EMBRITTLEMENT OF STEEL UNDER STRESS DURING IMMERSION IN MOLTEN SOLDER

During preliminary experiments, in connection with the effect of tensile stress on the rate of transformation of steel under isothermal conditions,<sup>4</sup> it was found that specimens immersed in molten solder, at temperatures between 200° and 400° C., were liable to fracture under tensile stresses of less than 10 tons/sq. in. The most probable cause appeared to be an attack on the steel by the liquid metal.

Since the phenomena of such attack were first observed by Dickinson<sup>5</sup> in manganese bronze, a number of papers have been published dealing with similar attack on ferrous metals. The evidence given is, however, somewhat contradictory. A paper by Genders<sup>6</sup> and a short survey in *The Metallurgist*,<sup>7</sup> both dealing with mild steel, report that molten solder has little effect, compared with that on copper and brass, and even then only at high temperatures, over 900° C. Similar investigations on alloy steels have been carried out by Van Ewijk<sup>8</sup> and by Smith and Forsyth,<sup>9</sup> and in both instances penetration is reported as occurring at quite low stresses and at temperatures in the region of 300° C. The only publication dealing with high-carbon, non-alloy steel appears to be that due to Austin,<sup>10</sup> who examined the tensile properties of a number of metals, including a wide range of steels, immersed in liquid solder. Even in this very full work, eutectoid steel does not appear to have been examined.

From the information contained in these papers, however, it appears that penetration by the liquid metal, at the grain boundaries of the steel, may occur if there is:—

- (1) Some degree of stress (tensile stress only seems to have been considered).
- (2) Contact with certain molten metals.
- (3) Elevated temperature.

All these conditions were satisfied in the tensile experiments under consideration. However, since the evidence on which these conclusions were based was not altogether satisfactory, it was considered advisable to carry out certain confirmatory experiments.

For this purpose specimens of steel A, after various surface preparations, were heated to 800° C. and quenched in a bath of molten solder. They were then placed in a tensile machine, the grips of which were immersed in the bath. This apparatus has been described elsewhere<sup>4</sup> and consequently further details are not given here. A load was then applied and the time for which the specimens supported the load without breaking was noted.

The surface conditions examined were:—

- (1) As supplied—thin oxide skin.
- (2) Pickled and then rubbed with emery cloth.
- (3) Copper-plated, after cleaning as (2), and
- (4) Nickel-plated, after cleaning.

The specimens were heated rapidly to 800° C. in a fairly heavy stream of dry nitrogen before quenching.

Nickel-plating alone was found to be effective in preventing failure, but the protection in this case was virtually complete, at least up to stresses of the order of 20 tons/sq. in.

The untreated metal was the next safest, while the cleaned and copper-plated metal proved to be very prone to attack. One copper-plated specimen broke almost immediately under a load of only 2 tons/sq. in. The penetration in such specimens was very heavy, the metal being riddled with transverse cracks which showed traces of solder along their whole length.

Microscopic evidence of penetration was not obtained with the specimens as supplied, but this was probably due to the very local nature of the attack, e.g. at some singular point of failure in the protective oxide layer.

The copper-plated specimens failed partly because the copper is itself easily attacked by molten metals, but also on account of its solubility in the solder, thus leaving a clean surface very liable to penetration.

For a given surface finish, the length of time, measured from the application of the load up to fracture, was found to vary with the applied stress. With specimens in the as-supplied condition and at 250° C. the following times were observed:—

2 tons/sq. in.—Unbroken after 1 hour.

10 tons/sq. in.—Failed after 12 minutes.

20 tons/sq. in.—Failed after 5 minutes.

The rate of attack thus increases rapidly as the stress increases.

When lead was used in place of solder, no penetration occurred, probably because the lead does not 'wet' the steel.

These results, taken in conjunction with the evidence available from other sources, indicate that intergranular penetration of steel by liquid metals may be very marked under suitable conditions. The most important factor being a state of stress, probably tensile, either internal due to quenching, or due to externally applied forces, the amount of penetration becoming greater under higher stresses.

Penetration only occurs with metals and alloys which 'wet' the steel, and hence the surface condition, since on it depends the contact between the metals, has an important effect.

#### Acknowledgments

The work described above was carried out as part of a programme under the auspices of the British Iron and Steel Research Association, to whom the author wishes to tender his thanks for financial aid.

#### B.R. Locomotives for Festival of Britain

DURING the Festival of Britain, three British Railways locomotives, employing steam, electric and diesel-electric power respectively, are to be on exhibition at the south end of Charing Cross Railway Bridge: access to these engines will be from within the grounds of the South Bank Exhibition.

The steam locomotive will be one of the new British Railways standard "Pacific" design intended for express passenger and fast freight trains. The electric locomotive will be one of the 0-6-6-0 type which is being constructed for use on the Sheffield and Wath and Manchester electrification. The mechanical parts of this and similar engines are being made in the railway shops at Gorton, Manchester. The diesel-electric locomotive was erected in the British Railways works at Ashford (the diesel engine and electrical equipment being supplied by the English Electric Co.). It is of 1,600 h.p. and is intended for use on express passenger trains.

<sup>4</sup> Jepsen and Thompson, *Jnl. Iron and Steel Inst.*, 1949, **162**, p. 49.

<sup>5</sup> Dickinson, *Jnl. Inst. of Metals*, 1920, **24**, p. 313.

<sup>6</sup> Genders, *Jnl. Inst. of Metals*, 1927, **37**, p. 215.

<sup>7</sup> *The Metallurgist*, 1931, Vol. 1, p. 107.

<sup>8</sup> Van Ewijk, *Jnl. Inst. of Metals*, 1935, **56**, p. 241.

<sup>9</sup> Smith and Forsyth, *Metallurgia*, 1946, **34**, p. 186.

<sup>10</sup> Austin, *Jnl. Inst. of Metals*, 1936, **58**, p. 173.



# New Laboratories for United Steel Companies' Research and Development Department



Swinden House.

THE establishment of the Swinden Laboratories marks the coming-of-age of the Central Research organisation of the United Steel Companies, Ltd. Originally conceived in 1930, the Central Research Department, as it was then called, quickly took shape under the able direction of Dr. Thomas Swinden and was housed in specially constructed laboratories situated at the Stocksbridge Works of the Company.

The development of the Department during the last 21 years falls naturally into three phases. Up to 1939, an excellent reputation was established for its work in the fields of chemistry, metallurgy and refractories technology, and an organisation was built up which was well equipped to meet the demands which were to arise, as a result of the war, during the second phase, from 1939-1945. As the war drew to a close and with the untimely death of Dr. Swinden in the autumn of 1944, the scope of the organisation became due for review and it was decided to expand its activities in certain directions, in order better to meet the changed circumstances with which the Company was faced.

In its enlarged form, it was intended that the organisation should be concerned with many and varied branches of science and technology: it was, therefore, agreed the new Director of Research should not be a specialist in any particular field, but should have a broad outlook, backed by a general background of experience. Mr. F. H. Saniter, who was appointed to the post early in 1945, was trained as a mechanical engineer and had previously served with both Steel, Peech & Tozer and Samuel Fox & Company, in connection with the development of alloy and special steels. Immediately prior to his appointment, he had spent five years with the Iron and Steel Division of the British Raw Materials Mission in the U.S.A., and so gained a useful knowledge of the organisation of the iron and steel industry in that country.

The new organisation was given the title of Research and Development Department, thus emphasizing the importance of the *application* of research to the improvement of industrial processes. One of the first steps taken in expanding the original Research Department was the creation of a group of development engineers to specialise in the main items of steelworks plant and equipment, and to keep abreast of new developments with a view to their early adoption where this seemed likely to prove

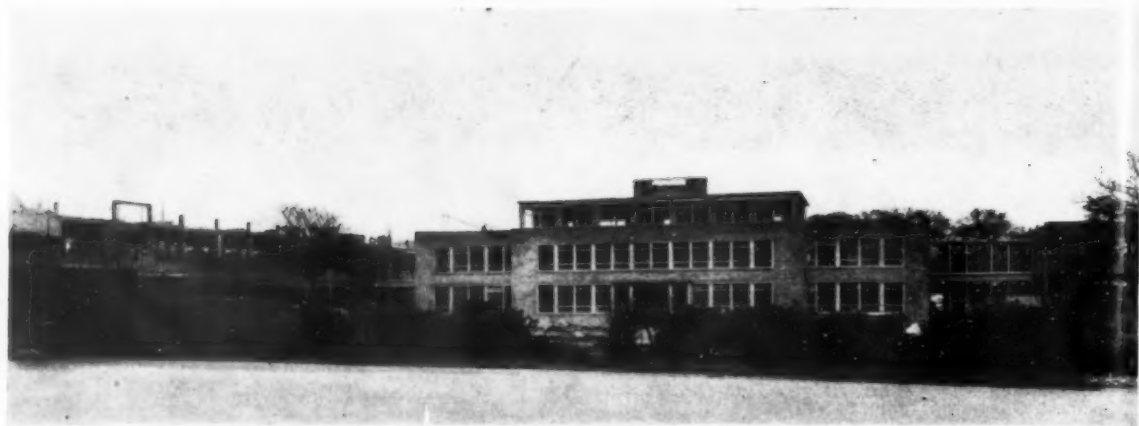
beneficial. It was also decided that more attention should be paid to the study of the raw materials on which the Company depends and a section dealing with petrology, geology, and ore-dressing was established. As renewed interest was being taken in open-hearth furnace design, a special group was formed to study this subject, and it has been provided with laboratories designed to provide basic data by means of aerodynamic and hydraulic models.

As a result of this expansion, it became evident that the Stocksbridge Laboratories would be inadequate to house the increased numbers and their equipment. Accordingly, in 1946, Swinden House (formerly Red House), Rotherham, was purchased as providing room for immediate expansion together with sufficient land for the erection of new laboratories. At the present time the laboratory facilities are divided between Stocksbridge and Swinden House, but as soon as the new buildings nearing completion at Rotherham become available, the whole department will be concentrated there.

## The Swinden Laboratories

Situated in ideal surroundings on the outskirts of Rotherham, the new home of the Research and Development Department is being built within the confines of a 15-acre, tree-encircled estate.

*Layout.*—As the new laboratories are situated on the South Yorkshire coalfield, the buildings have been arranged in four separate blocks inter-connected by corridor links of specially designed light construction and particular attention has been paid to foundations, in order to minimise the risk of damage due to subsidence. For convenience, the two outer blocks are referred to as A and B, respectively, the central block C, and behind it the workshop block D. Block A is to house the Metallurgical, Physics and Welding Sections of the Department; block B will be occupied by the Chemistry, Refractory and X-ray Sections; in block C will be part of the Administration, Development Group and Drawing Office, and Sections devoted to Petrology, Furnace Design, Fuel and Statistics. The workshop, block D, will house the Machine Shop, Steel Store, Steelmaking Plant, and special laboratories for work in connection with Aerodynamics, Water Models, Hot Model Furnaces, and for pilot plant.



The new laboratories taking shape. The centre of the picture is occupied by block C. Block "A" can be seen on the left and block B extends backwards on the right.

**Construction.**—The three main blocks are of steel-framed construction, with reinforced concrete floors and roofs. External walling is cavity construction throughout and, as far as possible, all internal walling is non-loadbearing to allow ease of alteration should this be required in the future.

A main service tunnel runs below all the ground-floor corridors and from this tunnel vertical ducts give services access to all rooms. To accommodate the very large number of service pipes associated with the Chemistry Laboratories, the floor of the block concerned is of double construction, the intervening space being occupied by the various pipes. The use of Appleby-Frodingham Castellated beams has made possible the maximum flexibility of this type of construction, the holes in the webs of the beams being most convenient for the passage of pipes.

The Workshop block D comprises two bays, each 150 ft. long and 45 ft. wide, the intervening space between them being roofed over to form a covered corridor. Rigid portal frames have been adopted for these bays with a centre monitor some 5 ft. high in each bay. The sides of the monitors are fitted with vertical glazing and large clerestory windows run down each side of each bay. The almost flat roofing to these bays is of "Bitumetal" insulated aluminium roof decking, water-proofed with mineral finish felt. Mechanical handling facilities in the form of two hand-powered overhead travelling cranes, each of two tons capacity are provided.

**Heating.**—In the main buildings the heating is by means of invisible low temperature radiant panels embedded in the ceilings. This method is ideal for laboratories since the wall space is entirely free of radiators and the like. Two sectional boilers in the basement provide hot water for heating and domestic use: these are arranged for alternative oil or gas firing. The accelerated hot water system is zoned, each zone being temperature-regulated by means of a direct acting outdoor thermostatic controller. In the Workshops block the heating is by overhead unit heaters, these are automatically controlled in groups by means of indoor thermostats.

**Original Buildings.**—In addition to the new modern laboratories, is the original large house of mellowed stone and brick construction, with its steeply inclined red-tiled roofs and its attendant outbuildings, now known as

Swinden House. On completion of the project, this building will house the Director of Research, the Department Secretary and his staff, Library, Information Officer, Photographic Section. The Conference Room, Dining Room, Canteen and Kitchen will also form part of this building. Other original outbuildings have been converted into a well equipped Ore Dressing Laboratory, Refractories Section Furnace Room, Sundry Workshops and stores.

On completion of the new laboratories, the total enclosed floor areas of the building will be 84,000 sq. ft., made up of 24,000 sq. ft. in the original buildings (Swinden House and its outbuildings), and 60,000 sq. ft. in the new laboratories. The cost of Swinden House and Laboratories will be approximately £250,000.

## Iron and Steel Educational Exhibition

THE need for a continuous intake of young people is vital to the continued existence of any industry. That this need is appreciated by the Iron and Steel Industry is shown by the arrangements which have been made by the Iron and Steel Federation for a travelling exhibition to visit nine steel-making areas during the next few months. Various aids to training—pamphlets, charts, films and other material—have been specially prepared for these exhibitions. School children in each area are being invited, and people interested in education and training will be able to meet men in the industry and discuss common problems. The industry is already doing much work in the training field, and still more remains to be done.

The itinerary of the exhibition is as follows:—

SWANSEA (Patti Pavilion)—February 14-20.

WARRINGTON (John Crossfield Memorial Hall)—March 7-10.

SHEFFIELD (Mappin Hall)—March 17-21.

BILSTON (Town Hall)—April 30-May 5.

GLASGOW (Y.M.C.A. Building, Bothwell St.)—May 15-21.

DARLINGTON (Bondgate Memorial Hall)—May 30-June 5.

BARROW (Hall to be decided)—June 12-16.

SCUNTHORPE (Youth Centre)—June 22-27.

CARDIFF (Westgrove Drill Hall)—July 4-10.

# NEWS AND ANNOUNCEMENTS

## The Institute of Metals: Awards of Medals

THE Council of the Institute of Metals has made the following awards of medals for 1951:

*The Institute of Metals (Platinum) Medal.* To DR. RANDOLPHE WILLIAM DIAMOND, Vice-President and General Manager of The Consolidated Mining and Smelting Company of Canada, Ltd., Trail, B.C., Canada, in recognition of his outstanding services to the non-ferrous metal industries in connection with researches on differential flotation as applied to the complex Sullivan ore, and as manager of the largest combined copper and lead producer in the world.

*The W.H.A. Robertson Medal.* To MR. CHRISTOPHER SMITH, Chief Metallurgist, James Booth and Co., Ltd., Birmingham, for his paper on "The Extrusion of Aluminium Alloys" ("Journal of the Institute of Metals," 1950, vol. 76).

*The Walter Rosenhain Medal* (first award). To PROFESSOR GEOFFREY VINCENT RAYNOR, D.Sc., D.Phil., M.A., Professor of Metal Physics at the University of Birmingham, for his outstanding contributions in the field of physical metallurgy, in connection with our knowledge of the constitution and formation of alloys.

## Extension of Underground Mining for Nickel Ores

In a letter to the shareholders, Dr. John F. Thompson, president of the International Nickel Company of Canada, Ltd., discloses that by 1953, the whole of the Company's nickel ore will be obtained by underground mining, as was the case prior to 1938. In 1937, the Company launched a project for the mining of the Froid-Stobie open pit surface ores and for the construction of larger concentrating, smelting and refining facilities to utilise these ores. This open pit project, as subsequently enlarged and accelerated, enabled the Company to achieve its high output during the war and post-war years. This large body of surface ores will soon be mined out, and in anticipation of this, the Company embarked more than ten years ago, on an extended programme to replace open pit capacity with further underground capacity.

The problem was to obtain and treat more than twice as much ore per year from underground as ever before. This has entailed extensive enlargement of the underground plants and the revamping of the metallurgical process. Entirely new methods of mining not previously undertaken had to be developed to make possible the economic utilisation of the lower grade underground ores which are available. This programme of expansion is being driven to conclusion with utmost speed. There is still much construction to be done, and a number of mining and metallurgical problems remain to be solved and tested in operation. Barring unforeseen interruptions, the full conversion to underground mining will be completed in 1953. The programme absorbed the major part of the \$100,000,000 capital expenditure during the last ten years. Further capital expenditures will be required to complete the programme and to maintain the increased capacity achieved. With an annual output of 13 million tons, the underground

mining operation will be unmatched in size by that attained in any non-ferrous base metal mining operation in the world.

## New Railway Wheel Plant

At the Trafford Park Works of Messrs. Taylor Bros. & Co., Ltd., the manufacture of railway wheels is being transferred to a new plant constructed as part of the Steel Industry's Development Plan at a cost in excess of £750,000.

The plant, which is the most modern of its kind in the world, has been designed to manufacture forged and rolled steel solid wheels and disc centres at a continuous rate of 60 per hour and will be in production within the next few weeks. With the new equipment it will be possible to produce a wheel within close tolerances so that subsequent machining may be reduced to a minimum.

Particular attention has been paid to improved methods of handling, which are automatic or semi-automatic, to ensure rapid transfer of material between the various items of plant. All items of plant are operated from two control rooms which are supplied with filtered air and the temperature is regulated to give the operators clean and healthy conditions protected from heat and steam.

A full description of the method of production, items of plant and auxiliary equipment together with photographs will be included in a subsequent issue.

## Fifty Years of Magnetic Attraction

It was in 1901 that the Rapid Magnetising Machine Co., Ltd. first introduced a drum-separator—carrying a yoke of electro-magnets for extracting ferrous from non-ferrous metals in scrap-yards. The Company—which now manufactures a wide range of magnetic separating and lifting equipment for almost every industry—recently celebrated its Golden Jubilee with a large gathering of employees, their wives and friends at a Dinner and Social Evening at the White Horse Hotel, Birmingham.

During its half-century of existence, the firm has expanded year by year and some 80 different forms of magnetic separators, from tiny machines weighing a few pounds, for examining fine grains, to an 8 ton mammoth, which removes iron from coal, are designed and manufactured in a modern self-contained factory. The Company also manufactures heavy-duty lifting magnets, which perform some of industry's heaviest tasks.

## Four-day Week for Vauxhall Motors

OWING to its present reduced allocation of sheet steel, Vauxhall Motors, Ltd. has found it necessary to place all its productive workers on a four-day week, as from February 12. This short-time week will be operated until the end of March, to enable the position to be investigated further, but should there be no change in the present allocation for the immediate future, the Company will have no choice but to reduce its productive force by something like a thousand men, including people from other departments which will be affected by the cut-down in production.



In his statement, Sir Charles Bartlett, managing director, stressed the seriousness of the situation for a productive community which, with improved manufacturing facilities, had hoped to play a greater part in the export drive than had previously been possible. Whilst every effort would be made to provide work for every possible man on every possible day, Sir Charles emphasised that they could not "make bricks without straw."

### George Cohen Sons & Co., Ltd.

THE Raw Materials Section of the Newcastle branch of George Cohen Sons & Co., Ltd., has been transferred to Coborn Works, Hebburn-on-Tyne, (telephone Hebburn 32331). These extensive and well-equipped premises will enable the company to provide an even better service in all matters concerning Ferrous and Non-Ferrous Scrap materials, Steel Sections, Plate Rails, Tanks, Sleepers, Steel and Cast Iron Piping, etc. The Machinery Section of the Newcastle branch will remain at Trafalgar House, Collingwood Street, Newcastle-on-Tyne, 1. (Telephone Newcastle 23313.).

### TI Directors Visit Brazil

MR. P. G. CAREW, an Assistant Managing Director, and Mr. Walter Hackett, Jr., a Director of Tube Investments, Ltd., left Southampton on the *s.s. Andes*, on January 20, to consult with customers and study market opportunities in Brazil.

### Swiss Machine Tools

A. C. WICKMAN, Ltd., on January 1, assumed the sole U.K. agency for machines made by Usine Tornos, who specialise in sliding-head precision automatics. The range includes machines with capacities from  $\frac{5}{32}$  in. in diameter to 1  $\frac{5}{16}$  in. diameter.

## Personal News

MR. D. A. OLIVER, Director of Research to the B.S.A. group of companies, has relinquished his position as a Local Director of William Jessop & Sons, Ltd., and J. J. Saville & Co., Ltd., because of increasing pressure of work connected with the activities of the B.S.A. group as a whole. He is succeeded as Local Director by Mr. G. T. HARRIS, Research Manager of the Jessop-Saville companies.

MR. W. E. A. REDFEARN, a Special Director of English Steel Corporation, Ltd., has been elected Chairman of the Alloy Steels Association in succession to the late Major Guy S. Newton. Mr. Redfearn is also President of the National Association of Drop Forgers and Stampers.

THE UNITED STEEL COMPANIES, LTD., of Sheffield announce that they have appointed MR. LESLIE FLATT, C.I.E., V.D., B.Sc.(Lond.), M.Inst.C.E., M.I.Mech.E., M.I.Loco.E. as Technical Consultant. He will be concerned with the Railway Materials produced by all branches of the Company, and particularly those produced at the Workington Iron & Steel Company, Cumberland, and Steel, Peech & Tozer, Rotherham. MR. C. F. RYAN, M.B.E., B.A.(Oxon.), A.M.I.Mech.E., A.M.I.Loc.E., has been appointed Chief of Development (Railway Materials) by the Steel, Peech & Tozer branch of The United Steel Companies, Ltd.

MR. W. C. F. HESSENBERG, M.A., F.I.M., has been appointed Deputy Director of the British Iron and Steel Research Association, of which Sir Charles Goodeve F.R.S., is Director. Mr. Hessenberg has been Head of the Association's Mechanical Working Division since March, 1947, and retains this position.

THE MOND NICKEL CO., LTD., announces that MR. L. H. COOPER has been appointed Chairman and MR. L. K. BRINDLEY, Managing Director. MR. G. ARCHER and MR. A. PARKER HAGUE continue as Directors, and MR. I. A. BAILEY, DR. L. B. PFEIL and DR. A. G. RAMSAY have also been appointed Directors.

MR. J. B. THOMAS, F.C.A., Deputy Chairman and Managing Director of Hadfields, Ltd., East Hecla Works, Sheffield, in consequence of his retirement is relinquishing these appointments at the end of the present month and will be succeeded by MR. HAROLD HUMPHRIES, Deputy Managing Director of the Company.

TUBE INVESTMENTS, LTD., announces that the following have been elected to the Board:—MR. E. D. E. ANDREWES, MR. T. J. BOULSTRIDGE, MR. P. GROVE. It is also announced that, on the resignation of the Secretary, MR. A. B. I. DICK, to devote his whole-time energies as Managing Director of the TI subsidiary, Talbot Stead Tube Co., Ltd., MR. I. TURNER has been appointed Secretary.

MR. R. PARKER, Assistant Lecturer in Metallurgy, University College of Swansea, formerly employed by the Appleby Frodingham Steel Company, Scunthorpe, has been granted a post-graduate travelling scholarship in Extraction Metallurgy, awarded by the Nuffield Foundation. He will be travelling in U.S.A. and Canada, visiting various plants during the four months commencing June of this year.

## Obituary

We regret to announce the following deaths:—

MR. R. C. STANLEY, Chairman of the International Nickel Company of Canada, Ltd., who died on February 12th. Associated with the International Nickel Company from its formation in 1901, and its leader for the past twenty-eight years, Mr. Stanley was virtually the architect of what is to-day one of Canada's foremost enterprises, an achievement which placed him in the front rank of the world's industrialists. He resigned the Presidency two years ago, but at the time of his death Mr. Stanley was Chairman of the Board, an office to which he was first elected in 1937. Not only because of his association with the Nickel Industry, but also as a Director of other important Companies, as a prominent member of many learned societies on both sides of the Atlantic, as the holder of numerous honours and awards, and as a supporter of many philanthropies, Mr. Stanley will be missed by a wide circle of friends in the U.K., Canada and the U.S.A.

SIR HARRY HARLEY, C.B.E., M.I.Prod.E., Vice-Chairman of the Council of the Production Engineering Research Association, who died on January 19th, 1951, during a journey to Australia. Sir Harry was founder of Coventry Gauge and Tool, Ltd., and at the time of his death was Deputy Chairman and Managing Director.

MR. G. C. TAITE, M.I.Mech.E., Director of Follisain Wycliffe Foundries, Ltd. and formerly Chairman and Managing Director of the Wycliffe Foundry and Engineering Co., Ltd., who died recently after a long illness.



# RECENT DEVELOPMENTS

## MATERIALS : PROCESSES : EQUIPMENT

### British Hard-drawn Steel Pellets for Cleaning and Peening

THE developments, in America, in the manufacture and use of hard-drawn steel pellets, primarily for the surface peening of springs and other articles, to obtain improved fatigue resistance, has been described in the Technical press, (e.g. H. H. Miller, S.A.E. Journal, August, 1949, and D. H. Cargill, Iron Age, 1950, April, p. 95). This new material, comes as the latest of a long line of materials which have been suggested at one time or another for shot blasting, cleaning or peening operations, and is now manufactured in this country by Bradley & Foster, Ltd., Darlaston, the well-known manufacturers of metallic abrasives.

The old process of "sand blasting," first applied to castings over fifty years ago, has now developed into a very important industry. The old idea that any abrasive material was suitable for shot-blasting purposes has been replaced almost completely by the newer concept of "fitness for purpose." No longer is shot and grit confined in application to the mere removal of scale, rust or unwanted coatings from iron castings and steel work. To-day, there exists a range of metallic shots and grits from which the user can choose; by his choice, he can exercise a direct control upon the surface properties of his product. Metallic abrasives are no longer used only by the foundryman, stone-cutter, engraver, or vitreous enameller, but are now the tools of the precision engineer who is interested in improving the performance of some highly-stressed machine part. The peening hammer of the blacksmith has been replaced almost entirely in this function by air blast and mechanical shot peening methods employing metallic shot.

The modern development of shot peening to improve the fatigue strength and endurance limit of highly-stressed steel machine parts has made big demands upon

the quality of shot. The newly developed hard-drawn steel pellets have proved to be first-class peening material from the standpoint of uniformity of physical properties, maintenance of size and useful life.

#### General Uses of Pellets

Hard-drawn steel pellets, although chiefly used for the peening of highly-stressed steel shafts, springs, gears and splines are also of interest for cleaning purposes. In this respect, their characteristic toughness results in a long working life, which in certain circumstances may offset the cost of this type of abrasive as compared with cast steel or iron shot and grit. The breakdown rate of pellets is extremely slow and thus the material remains true to size for a longer period than other types of shot. Steel pellets have a lower surface hardness than chilled iron abrasives and for this reason it is claimed that they do not cause so much wear on the equipment used in blasting. With the ever-increasing trend to high speed in shot-blasting machinery, this can result in substantial economies.

Another advantage which is claimed for pellet abrasives is that they can be manufactured in almost all ductile metals and alloys, e.g. stainless steel pellets are being used for specialised cleaning purposes in the case of stainless steel and non-ferrous articles. Such pellets are applied to the cleaning of bronze and brass castings where the presence of iron impacted in the surface might lead to objectionable stains during the finishing process. Non-ferrous castings are improved and are left with a natural pleasing surface colour. In addition their machining has been speeded up and troubles due to tool breakage at hard spots has become non-existent.

The potential uses of blasting pellets are legion, and at present largely unexplored. The full importance of the development will only be realisable in the future. For the present, the application of steel pellets to the peening process is certainly their main use.

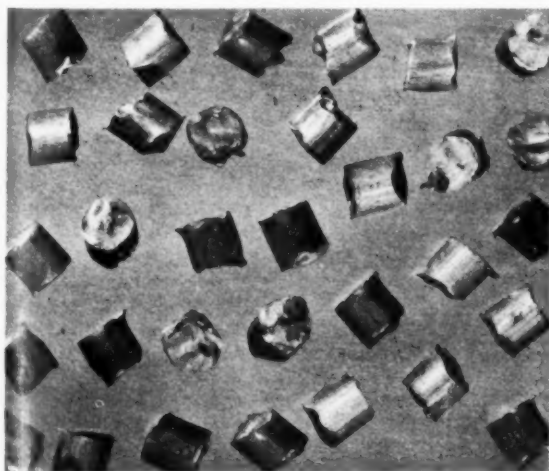


Fig. 1.—Hard-drawn steel pellets

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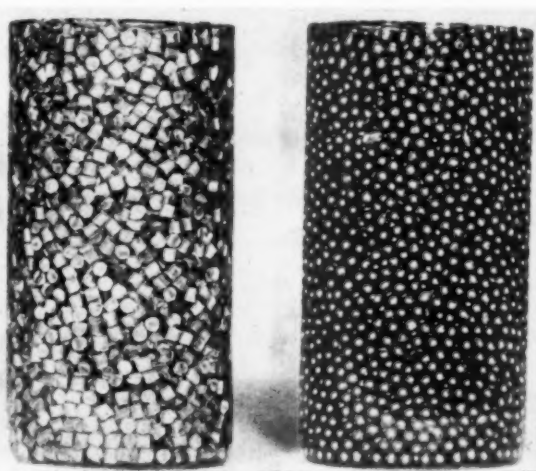


Fig. 2.—Comparison of hard-drawn steel pellets and cast-iron shot.

× 1

### Hard-drawn Steel Pellets for Peening Purposes

Hard-drawn steel pellets for peening are made in a machine which has been designed to cut wire accurately, and without flash, into lengths equal to the diameter of the wire. The sizes regularly produced are pellets 0.0625 in., 0.055 in., 0.0415 in., and 0.0313 in. diameter. Other sizes can be made available to customers' requirements.

The wire from which the pellets are produced has a tensile strength of 100-130 tons/sq. in. and a hardness between 400 and 500 Brinell. As supplied, the pellets are cylindrical in shape. A typical example at a magnification of five diameters is illustrated in Fig. 1.

When using hard-drawn steel pellets for the first time for a peening operation, it is necessary to blunt the sharp corners by blasting scrap or, better still, by using first in a forging or castings cleaning plant. Small day-to-day additions or "make-up," to a peening plant already operating on pellets, can be made in the form of new pellets without causing difficulties. However, for jobs where there might be severe surface requirements, such as peening aircraft parts, it may be desirable to use well-conditioned rounded particles. The ultimate shape of each pellet becomes, in use, a sphere. The illustration Fig. 2 shows a comparison of hard-drawn steel pellets, and ordinary chilled shot.

Extensive trials of hard-drawn steel pellets for the peening of springs have been reported by the General Motors Corporation, Buick Division, U.S.A., and others. The results of all these trials, which have been amply confirmed already in this country, show the consumption of pellets to be only one-tenth of the usage of chilled shot of ordinary quality for the same operation.

### Advantages of Pellets

(1) *Uniformity.* Steel pellets are ideal from the point of view of uniformity of physical properties, size maintenance in use, and life. Uniformity is essential for good peening application, so as to secure regular response to the improvements in endurance life of the treated steel machine parts. The use of steel pellets removes many of the objections to shot peening. It allows a much better control of the process which should result in a new attitude towards peening which, in turn, will probably make possible many new applications.

(2) *Efficiency.* The uniform toughness and particle size enables machines for blasting, peening and cleaning to be worked at optimum production efficiency. The physical characteristics of hard-drawn steel pellets are such that less wear of working parts of both blast and mechanical shot projecting machines takes place. The improvement in working speed and the reduction in stoppages for repairs combine to give a much greater plant efficiency.

(3) *Cost.* For the peening of springs, the value of hard-drawn steel pellets compared with chilled cast iron was in the ratio 10 : 1. Whilst the cost of pellets is much higher than that of chilled cast iron shot it is not in such a high ratio as this; the savings possible depend upon the application. The cost advantages over other peening materials may only be assessed when full account is taken of the long life and efficiency, with a consequent reduction in handling costs. Each new application must be thoroughly investigated by actual trial before the true cost advantage is decided upon.

(4) *Applicability.* Blasting pellets, which can be obtained in a variety of metals, give a wider range of

materials now available to the engineer for the cleaning and peening of machine parts and castings. Pellets may be produced economically in metals which could not be produced as graded shot and grit. For this reason, this new development may be regarded as enlarging considerably the applicability of shot-blasting.

*Bradley & Foster, Ltd., Darlaston*

### Carbo-nitriding

ORIGINALLY, case-hardening of steel components was achieved by heating in a solid carburising compound, to increase the surface carbon content, followed by quenching. A further development, which has been in operation for many years now, is the cyanide process, in which carburisation of the surface is effected by immersion in a bath of molten cyanide for a sufficient length of time to produce the required depth of case. In this process, both carbon and nitrogen are introduced into the steel, the concentration of both constituents being greatest at the surface and decreasing progressively towards the core. The salt-bath method was followed



Fig. 1.—A typical batch-type furnace for carbo-nitriding. The equipment furthest from the camera is for quenching purposes.

by the gas-carburising process in which the components are heated in a carburising atmosphere instead of in a solid compound or liquid bath. All three processes, solid, liquid and gaseous, are widely used to-day, and to them must now be added a fourth—carbo-nitriding, in which a gaseous atmosphere is used to introduce both carbon and nitrogen into the surface of the component, thus producing a case having characteristics similar to those produced in the cyanide bath.

The presence of nitrogen increases the degree to which the case can be hardened. Thus, the carbo-nitriding process—like salt-bath cyaniding—results in the formation of a "hardenable" case at treatment temperatures some 100° C. lower than those used in normal carburising practice. This lower treatment temperature is advantageous in reducing the amount of distortion. Furthermore, the resistance of the case to wear is greater than that of a comparable case produced by carburisation alone.

The carbo-nitriding process is particularly suited to the production of hard, shallow, wear-resistant cases which

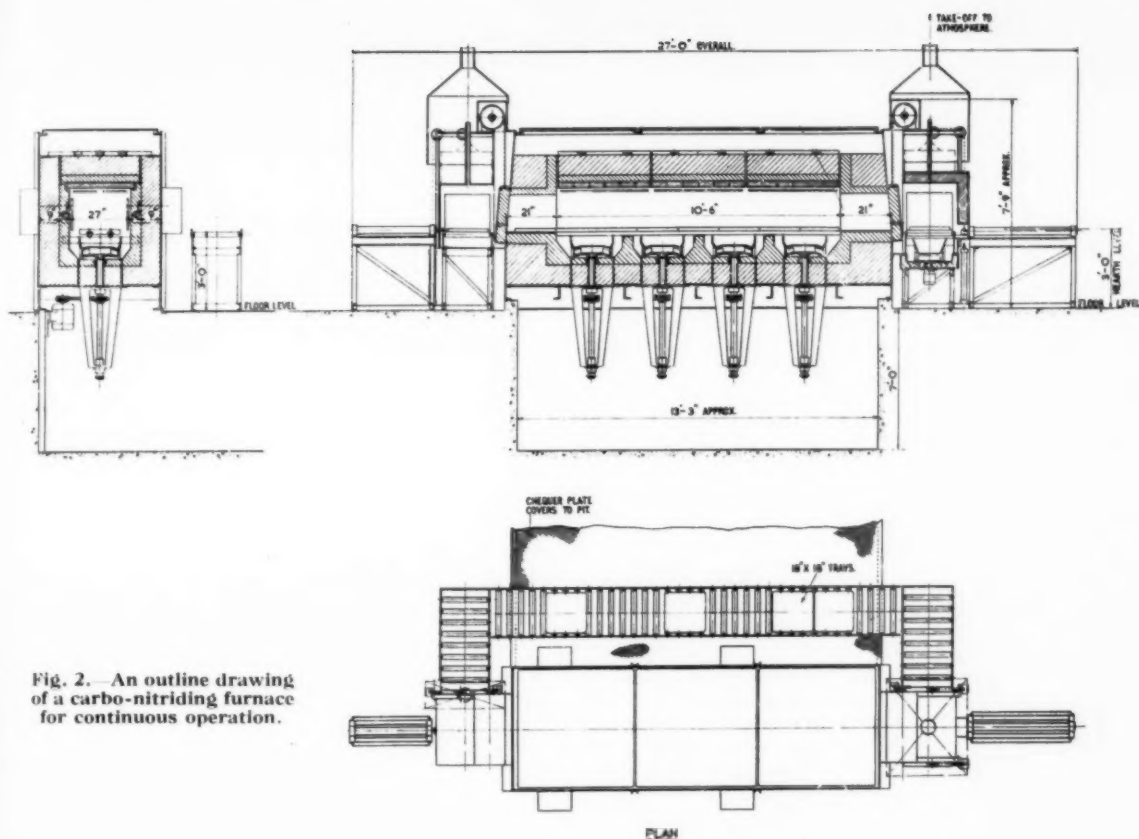


Fig. 2. An outline drawing of a carbo-nitriding furnace for continuous operation.

have general characteristics comparable with those obtained by treatment in a cyanide bath. Broadly speaking, for a given temperature of treatment, the case depth obtained by carbo-nitriding is similar to that obtained in a salt-bath, but the surface concentrations of nitrogen and carbon may be varied in carbo-nitriding by suitable adjustment of the rate of addition of ammonia and hydrocarbon to the atmosphere. The gaseous process can result in a much greater economy for certain classes of work and, when used in conjunction with continuous furnaces, produces a greater "through-put" of work which, if desired, can be fully heat-treated in a protective atmosphere.

The atmosphere suitable for the process consists of a carburising gas to which ammonia is added. The carburising gas consists essentially of a mixture of carbon monoxide, hydrogen and nitrogen and is generated by passing town gas and air over charcoal, or other catalyst, contained in a retort heated to approximately 1000° C. Propane and ammonia are added to the gas so generated, the combined amounts being of the order of 10%. This mixture is then re-circulated over the work at, say, 850° C. for sufficient length of time to produce the required depth of case. The work may then be quenched and tempered, or given an isothermal treatment to develop the required properties.

Furnaces for carbo-nitriding may be either of the batch- or the continuous-type, and are of similar design to those used for gas carburising. Usually, where a quench or isothermal treatment is given to the components after carbo-nitriding, the bath is made an integral

part of the furnace, so that the work is maintained in the atmosphere right up to the time of immersion. A batch furnace suitable for the process is shown in Fig. 1, the work being supported in heat-resisting trays in a gas-tight heat-treatment chamber, and the gas mixture forced over the charge by a fan situated in the base. Continuous furnaces may be of the "pusher" or "rotary-hearth" type: in the former, the work is normally loaded on to trays, or suspended from skids. An outline drawing of a continuous furnace suitable for carbo-nitriding followed by isothermal treatment is shown in Fig. 2. Recirculation of the gases within a continuous furnace is essential, and suitable gas-locks must be provided to protect the furnace atmosphere during charging and discharging.

*General Electric Co. Ltd., Magnet House, Kingsway, London, W.C.2.*

### New All-Purpose Moulding Boxes

THE keynote of the design of the new all-purpose moulding boxes now in production by the Paget Engineering Company is lightness and adaptability. Two standard models are produced: (1) general purpose moulding boxes, and (2) machine moulding boxes. The frame of the general purpose model is a one-piece pressed steel section, designed for maximum sand-keying, with frame, ribs and stays all deep-swaged for extra rigidity. Standardisation of parts enables extreme accuracy in siting locating-pin centres. A link-type clamp, with eccentric bush to give quick and positive lock action, can

be supplied. Twenty standard sizes of box are available, ranging from 2 ft. square, upwards, and from 4 in. to 10 in. in depth, with all component parts interchangeable. The machine moulding box is similar in design, but ribs and stays are not fitted as standard. A "D" type handle is supplied, and spigots for clamps are available, if required. The twenty-two standard sizes range from 1 ft. square, upwards, and from 3 in. to 6 in. in depth.

*The Paget Engineering Co. (London), Ltd., Braintree Road, South Ruislip, Middlesex.*

### Zirconium Metal

UNTIL recently, only limited supplies of zirconium metal were available in this country, but production on a commercial scale has recently been started by Murex, Ltd. Even now, however, full production has still to be attained. At the moment, sheets down to 0.005 in. in thickness, 6-7 in. in width, and 2-3 ft. in length are being made, and it is expected that sheets up to 12-15 in. in width will be available in the course of the next few months. Rods down to 2 mm. diameter can be supplied and drawn zirconium wire may soon become available.

One of the most important properties of zirconium is its excellent resistance to corrosion. Hydrochloric acid and fused alkalis cause practically no attack on the metal, whilst its resistance to attack by nitric, phosphoric and sulphuric acids is only slightly less than in the case of tantalum. This property renders it very suitable for use in chemical plant where corrosion resistance is required. It is also employed in surgery, for the same reason, and because of its further convenient property of attaching itself permanently to the surrounding flesh.

Zirconium has exceptionally good "getter" properties which will tend to make its use in electronics widespread. It is used as grid emission inhibitors and can, in many cases, replace tantalum or molybdenum.

*Murex, Ltd., Rainham, Essex.*

### Multiple Spot Welding Developments

DEVELOPMENTS in recent years in connection with resistance welding on mass production have shown a definite trend towards larger and more specialised machines. In such fields as motor car production, where assembly sections often call for as many as 200 spot welds, a great need is felt for an automatic machine capable of producing this large number of spots in a continuous cycle of welding operations. Both technical and economic aspects of such specialised machines would seem forbidding, but where labour costs are a vital factor in production, as in the United States, they have more than justified the initial cost. The present trends of rising costs in this country have focused the attention of British industrialists on the question and equipment of this type has now been designed and produced by Philips Electrical, Ltd.

A compound method of operations is used whereby the actual welding force is applied by hydraulic means. Primary current to the multiplicity of welding transformers is controlled electronically by means of ignitron valves, and the time cycle of pressure, weld and forge, by a series of cold-cathode-type electronic timers, interlinked to give the desired timing frequency and cycle of operations.

Due to the complexity of the electrical load, and the wide divergence of power available in various production centres, the welding transformers and timing sequences

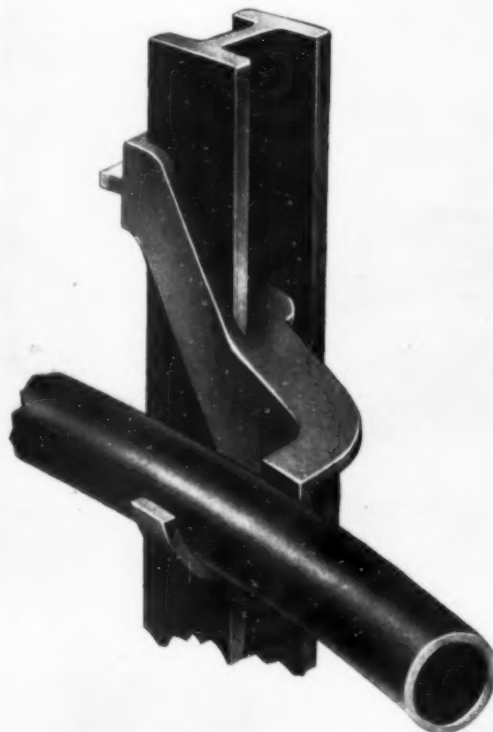
are so arranged that the speed of operation and the number of welds made is variable, and can be connected to the power supply in multiples commensurate with the power available. With a power supply of 250 kVA, it is possible to produce 200 spot welds in 30 seconds, using 12 cycles of welding time for each combination of welding points.

Higher quality of the product and a substantial reduction in cost are the chief advantages claimed for this equipment.

*Philips Electrical, Ltd., Century House, Shaftesbury Avenue, London, W.C.2.*

### Supporting Loads From Vertical Girders

AN ingenious clip, which has recently been introduced, is designed to support pipes of all kinds, pulleys, platforms and other articles from vertical girders and has the



unique feature that it is attached to the girder merely by placing in position and hammering home. Made in Wylcliffe Blackheart Malleable, the "Wynip" is cast in one piece and has been officially tested to carry a load of one ton. It is impossible for the "Wynip" to slip, as any increased load up to one ton merely causes the tapers on the clip to bite more firmly into the tapers on the girder. In spite of its rigidity, however, it can be removed by a light blow under the hook once the load is removed. The "Wynip" is supplied in a number of sizes to fit standard girder sections.

*Follisain-Wylcliffe Foundries, Ltd., Lutterworth, Nr. Rugby.*



# CURRENT LITERATURE

## Book Reviews

### METALS AT HIGH TEMPERATURES

By Frances Hurd Clark (U.S. Navy Material Catalog Office). pp. 372. U.S.A., 1950. Reinhold Publishing Corporation. Distributed by Chapman and Hall, Ltd., 56s. net.

ALL metallurgists and engineers who have to deal with the many problems that arise in the construction and operation of steam and gas turbines will heartily welcome the appearance of this book.

As is well known, the behaviour of a metal when subjected to stress at elevated temperatures cannot be forecast from a study of the results obtained in short time tests. A metal may fail due to creep if stressed for long periods at elevated temperatures, even though the stresses imposed are well below the limit of proportionality. The object of creep testing is to determine the maximum stress that can be applied at a particular temperature without the total deformation exceeding a certain value over a stated period of time. Such tests are very expensive and time-consuming and even a large research organisation cannot possibly hope to carry out tests on more than a small fraction of the high temperature materials that are available at the present time.

The author has set out to collect together, in one volume, high temperature data from a large number of sources, embracing the complete range of metals from plain carbon steels to super alloys. The data thus obtained has been presented in a logical sequence in both tabular and graphical form. She has been fortunate to have had access to data obtained by a large number of research organisations in the United States, much of which has not been published before. The scope of the book can be most readily appreciated from a study of the following brief summary of the chapters: (1) Introduction and theoretical aspects; (2) Test methods and equipment for elevated temperature testing; (3) Plain carbon and low alloy steels; (4) Chromium irons and moderately alloyed austenitic steels; (5) Highly alloyed austenitic steels; (6) Cobalt-base alloys; (7) Nickel-base alloys; (8) Non-commercial alloys; (9) Manufacturing processes; (10) Lower melting alloys (Lead, Magnesium and Aluminium alloys); (11) Sealing.

Innumerable results of creep, stress-rupture and fatigue tests are given for each class of alloy and the data is made more valuable by the inclusion, in the majority of cases, of such manufacturing details as type of furnace, method of deoxidation, forging and heat treatment practice, final grain size, etc. Other authors would do well to follow a similar practice. The presentation of the data throughout the book has been admirably executed and the inclusion of design curves where the results of really long time tests are available will be found most valuable.

The author has taken care to emphasise the need for really long time creep tests in order to avoid, as far as possible, the somewhat hazardous practice of extrapolation. It is stated, and rightly so, that tests should continue for at least 10% of the anticipated service life of a component. Such long time testing is essential before it can be assumed that the metal will be structurally stable throughout its life, or that any changes that

occur (such as precipitation of carbides) do not seriously reduce the creep strength.

The chapter on non-commercial alloys deals with a very large number of *ad hoc* tests which were carried out in the States under government sponsorship during the war. A vast number of alloys were made and the results of creep and stress-rupture tests are given in tabular form. A study of these results will enable research workers engaged on the development of new alloys to avoid alloys which have already been proved to be unsuitable.

The British metallurgist will welcome the use of both the Centigrade and Fahrenheit temperature scales throughout the text: he will find that this more than compensates for having to think in terms of pounds per square inch.

On the side of criticism, the following minor points may be mentioned. On page 305, under the heading Failures, it is stated that the incidence of turbine blade fatigue failures may be reduced by more careful design and elimination of vibration. No reference is made here or elsewhere in the text to the effect of the damping capacity of metals together with the damping effect obtained from mechanical blade fixing (serrated type roots). More detailed information on this important property of metals is highly desirable.

In the chapter on scaling, it is rather surprising that the author has omitted all reference to the corrosive effect of high vanadium bearing fuel ashes as this is one of the most formidable problems facing the gas turbine engineer at the present time.

As a book of reference this volume has no equal. It is in fact the first book to be published that contains data on almost all the known high temperature metals. Together with the extensive references given at the end of each chapter the reader can obtain almost any information he may require regarding the properties of commercially available metals.

S. H. FREDERICK.

### CHEMISTRY RESEARCH 1949

Published by His Majesty's Stationery Office for the Department of Scientific and Industrial Research. 3s. (75 cents U.S.A.), by post 3s. 2d.

THIS publication which appeared at the end of December gives an account of the progress of research at the Chemical Research Laboratory, Teddington, during 1949. Several of the projects are of interest to metallurgists, especially those dealing with the corrosion and protection of metals. A corrosion inhibitor has been developed which has proved effective in reducing corrosion in the cooling systems of motor vehicles, with cast-iron cylinder heads and blocks, when mixed with glycol anti-freeze preparations. The inhibitor, which consists of sodium benzoate mixed with a smaller proportion of sodium nitrite has been road tested with satisfactory results. Rubber latex, to which the above mixture has been added, can be used to form a protective film on machined parts.

Fundamental work on sulphate-reducing bacteria has provided knowledge which has been applied to practical problems of pipe laying, and the protection of the pipes against corrosion.

Samples of antimony, chromium, iron, lithium and tantalum have been examined analytically and a beginning has been made in forming a stock of metals of high purity.

#### PHILIPS' "PRACTICAL ARC WELDING COURSE"

2nd edition. 226 pp., 185 illustrations, numerous tables, 16 appendices. Philips Electrical Ltd. (Industrial Dept.), Century House, Shaftesbury Avenue, London, W.C.2. 7s. 6d., post free, or from booksellers.

FOLLOWING up the enthusiastic reception of the first edition, supplies of which are completely exhausted, a revised and greatly enlarged second edition of this book has just been completed. The new edition is a practical text book, compiled with the aid of many well known experts, setting out clearly and concisely the essential principles of modern arc welding. It incorporates considerable theoretical data to supplement the chapters on the practical aspects of arc welding. The text matter is well laid out and supported by a considerable number of diagrams and illustrations. It covers in logical order every phase of arc welding from its fundamental principles and practical welding technique to weld examination and costing, and will prove of equal value to the instructor, student, foreman-welder and executive.

### Trade Publications

IF one is used to thinking in terms of mass production of some thousands of components or machines per year, a certain amount of mental readjustment is necessary when considering the activities of the shipbuilder, rolling-mill engineer, or blast-furnace builder, whose outputs in terms of units per year may be of a very low order. It is not surprising to note in "Blast Furnaces," recently issued by Ashmore, Benson, Pease & Co., Ltd., Stockton-on-Tees, that this souvenir will only be re-issued quinquennially. The present edition, which covers two decades, recalls a number of forward steps in the development of the blast-furnace from the Josephine Furnace, at Fords, Dagenham (1930-34)—when history was made in British furnace design with the introduction of mechanisation and automatic control, now a feature of every modern furnace—to the furnaces now under construction incorporating the latest advances in blast furnace practice.

GEAR shaving has been developed principally as a means of finishing gears having limits of accuracy and finish comparable with gears which have been profile ground, and is particularly applicable to the automobile industry, where the elimination of profile grinding has made possible considerable economy. A leaflet giving a brief account of the process together with details required when ordering shaving cutters is obtainable from The David Brown Tool Company, Park Works, Huddersfield. Is the "Sabenite" Tungsten Carbide Tipped Tools Catalogue issued by Sanderson Bros. & Newbould, Ltd., Sheffield, details are given of the standard tools and tool tips available, together with extensive information on their use. Apart from notes on machining technique, brazing methods suitable for tipping tools, methods of grinding, and causes of premature failure are discussed.

AN enlarged and revised edition of "The Use of Zinc Pigments in Exterior Paints" has recently been issued by The Zinc Pigment Development Association, Lincoln House, Turl Street, Oxford.

The more important additions now made to the original text (which appeared in 1947) are as follows:—the outdoor tint-retention tests recently conducted by the Z.P.D.A. are reported and discussed; zinc chromate paints are described in a new section which outlines their advantages when used as primers on light metals and iron and steel; under the heading "Zinc Dust Paints," mention is made of the use of special vehicles which enable the dry paint film to approach very closely to an unbroken metallic coating; the section on zinc oxide and titanium has been expanded in view of the increasing use of mixtures of zinc oxide and titanium dioxide pigments in finishing paints.

CROFTS (Engineers), Ltd., Bradford, have served industry's requirements in the power transmission field for over 50 years. Reorganisation of the Company's resources has now been developed to a degree whereby certain requirements can be satisfied immediately from extensive stocks. Details of the items available from the "Over the Counter Sales Division" are given in an illustrated leaflet recently issued.

THE first number of the Metro-Cutunit Bulletin, issued by Metro-Cutunit, Ltd., 160, Piccadilly, London, W.1, recently made its appearance, to be followed at irregular intervals by others. Details of the various grades of Atomit Hard Metal (cemented carbide) are given, together with the purposes for which each is suitable.

WE have received from the Cambridge Instrument Co., Ltd., 13, Grosvenor Place, London, S.W.1, a recently published folder, No. 65A, in which details are given of the latest types of Mercury-in-Steel Thermometers for indicating or recording at a distance the temperatures in a wide variety of applications, up to 1,000° F. or 600° C.

### Books Received

"Metal Spectroscopy," by F. Twyman, F.R.S. 569 pp., 144 illustrations, 28 tables, 2 appendices. Charles Griffin and Co., Ltd., London. 1951. 50s. net.

"Welded Deck Highway Bridges." This book is devoted exclusively to information obtained from the designs entered in the "Welded Bridges of the Future, 1949 Award Program." 247 pp., numerous illustrations. Published by The James F. Lincoln Arc Welding Foundation, Cleveland, Ohio, U.S.A.

"The Structural and Mechanical Properties of Metals," by Bruce Chalmers, D.Sc. The second of a series of Monographs on Metallic Materials published under the authority of the Royal Aeronautical Society. 132 pp., 89 illustrations. Chapman & Hall, Ltd., London. 1951. 18s. net.

"Conductimetric Analysis at Radio-Frequency," by G. C. Blake, F.Inst.P. 109 pp., 40 illustrations, bibliography. Chapman & Hall, Ltd., London. 1951. 15s. net.

"Five Years of Co-operative Research—1946-1950." This booklet provides a brief account of the work carried out by the British Iron and Steel Research Association during its first five years of effective operation. 23 pp., 11 illustrations. Published by B.I.S.R.A., 11, Park Lane, London, W.1.

# METALLURGICAL DIGEST

## How to Weld Corrosion Resistant Material

By W. G. Scherer

**W**ELDING applied in the fabrication of stainless steels has many advantages, but it must be recognised that the weld area is the critical area so far as corrosion resistance is concerned. The metal has been heated to the point of fusion, with consequent changes in the metallurgical structure and frequently in the chemical composition of the base metal. The introduction of filler metal also complicates the problem.

Preparation for welding includes cleaning and bevelling. Any standard method of cleaning is suitable for most materials. Bevelling can be done by (1) machining, (2) punching, (3) arc cutting with the hollow rod, and (4) cutting with carbon arc. The smoothness of the bevelled edges will be in this order.

### Nickel and Nickel-clad Materials

Nickel can be cut satisfactorily by all the above methods except the carbon arc. Butt welds should have a 60° groove—30° on each plate. The root pass should be made with a small rod and the second pass with a heavier build-up rod. A coated rod of pure nickel should be used for all welds. After the groove has been filled from the bevelled side, the weld should be chipped from the opposite side and then welded. For sections  $\frac{1}{2}$ – $\frac{3}{4}$  in. thick the nickel should be preheated to improve the flow of the metal. The current density can be as high as the rod will carry, up to the point that the coating on the rod is lost. Increasing the preheat will permit a higher current density.

With nickel-clad steel the danger of iron pick-up is the major problem and the technique is developed to control this. The steel side is bevelled down to within  $\frac{3}{32}$  in. of the nickel layer. The first pass is made with a steel rod, taking care not to burn through into the nickel. Successive passes fill the groove on the steel side and the work is then reversed and nosed out on the nickel side into the steel layer. The groove must be cut to the region of

complete penetration—say about  $\frac{1}{8}$  in. into the steel. Using a pure nickel rod, the first pass is made on the nickel side and a second pass fills the groove. The final bead should be 99–100% nickel.

### Stainless Steels

Most work in stainless steels requires special cleaning methods. Mechanical cleaning by sand blasting combined with chemical cleaning in a bath of 20% nitric acid and 4% hydrofluoric acid will remove all stains and also passivate the metal. Bevelling for the weld can be done as for nickel, machine cutting being preferred. The welding rod should be slightly richer in alloy content than the base metal. The use of titanium or niobium as a stabilising element against carbide precipitation is now well established, as is the use of special grades of stainless steel very low in carbon content. With the lighter gauges of stainless steel, helium shielded arc welding offers the advantage of faster welding with less danger of burning through the metal.

Stainless-clad material can be prepared as for nickel. The welding starts from the steel side. The rod should be highly alloyed, preferably 25–20 chromium-nickel. The same caution as with nickel-clad steel must be exercised against contaminating the weld metal on the stainless side.

### Nickel Alloys

Monel and Inconel are not cut with the flame, but can be cut with the carbon arc; a single carbon rod is used ground to a pencil point. The current can be about 400–600 amps. The metal is most easily cleaned by making a paste of the following composition:

Fuller's earth . . . . .	10 lb.
Lampblack . . . . .	1 lb.
Hydrochloric acid, 20° Bé . . .	1½ gal.
Water . . . . .	1½ gal.

The mixture in the form of paste is applied at room temperature with a paint brush and permitted to stand for at least one hour, or preferably overnight. It is then rinsed off with warm water.

For solid metal the rod should be of the same composition. With the clad metal, technique and precautions

are similar to those for clad nickel. Welding of Inconel clad material can be done with a rod of 80:20 nickel-chromium for the alloy side; pick-up of a few per cent. of iron, during the welding, combined with the loss of a few per cent. of chromium, will bring the weld metal to about the same composition as the base metal.

### Copper Alloys

Silicon bronzes of the type of Everdur, Herculoy and Olympic bronze, are best cut with a carbon arc or the hollow rod. They can be arc welded with a rod of the same composition as the base metal, or with the carbon arc and a base wire of the same composition. In the latter case the wire supplies filler metal only. The weld can be cleaned with hydrochloric acid.

While copper can be cut with the carbon arc or the hollow rod, machine cutting is much to be preferred. Carbon arc welding is usually preferable on copper, with silver brazing for critical work and small pieces, and the standard alloy brazing for heavier or general work. The work can be forged while still red hot, to improve grain structure.

## Argon or Helium for Inert Gas Welding

By J. Berryman

**A**N answer to the above question must be based on a proper understanding of the nature and function of the two gases as they are being used in welding. The two are indistinguishable on the basis of chemical inertness. The greater density of argon and therefore its presumed better weld blanketing characteristics are illusory as both argon and helium reach a high temperature in the arc zone with the result that both rise very rapidly and with little difference in the lifting rate between them.

The essential difference between the two gases is that the voltage per unit of arc length in helium is very much greater than it is in argon. This means that in helium the arc is hotter, penetration is more effective and deeper, travel speeds can be appreciably faster, and in many cases, adverse

From *Materials and Methods*, 1950, 32, No. 2, 61.

From *Iron Age*, 166, 155–157, 12th October, 1950. (Abstracted in *Light Metals Bulletin*, 12, No. 25, 1950.)



heat effects upon the work can be minimised. At the same time, particularly in metal arc welding, the arc in helium is harsher, more inclined to spatter and somewhat less comfortable in operation.

Generally, therefore, the nature of the work will determine the type of welding required, and so determine the shielding gas best suited for the job. Heavy work, requiring much weld metal, work with high heat conductivity, work where maximum speed and penetration are required are better accomplished with helium. Thin material where burn-through would be likely, appearance work where smooth-

ness and minimum spatter are essential, other jobs where lower heat and smoother operation are required are better done with the argon arc.

For work falling between the above categories, the rational procedure is to use a mixture of argon and helium. By proportioning the two in a range from 6 to 1 to almost 1 to 1, any desired combination or balance of characteristics can be had. While this practice has had little importance in tungsten-arc operations, it has been valuable when a consumable electrode is used, where speed and penetration are a more complex function than with the non-consuming electrode.

## Electric Spark Treatment of Hard Alloy Tools

THE Russians are devoting much attention to economy of so-called deficiency raw materials. In tool sharpening and finishing, for example, they have for some time been searching for an alternative to the ordinary abrasive methods, especially for the hard alloy tools, as the principal abrasive used for the purpose, both black and green carborundum, is definitely a deficiency material. In the same category are to be included diamonds, with all their varied industrial applications of grinding, truing, and for tools generally. In *Stanki i Instrument* 1959, 21 (10), pp. 3-6 M. N. Ulitin describes the electric-spark method of sharpening and finishing hard alloy tools, his article being preceded by an editorial note emphasising the importance of the subject. At the same time, the note indicates the existence of two more or less rival schools in Russia: one in favour of the electric spark and the other preferring the anodo-mechanical method as a substitute for abrasive grinding. The Russian Ministry of Machine Construction is arranging for further tests of both methods and meantime invites discussion of Ulitin's article.

Some of the basic features of the electric spark process have already been described in the author's Russian patents Nos. 75056 and 78862 and are here somewhat elaborated. The set-up comprises an existing grinder, the spindle of which has been specially adapted to connect up with an electric circuit designed to give potentials varying from 20-220 v., current 0.1-150 amp., and capacity of 1-400 mfd. Speeds of rotation of the electrode tool (disc) could be 5, 10 or 15 m./sec., and

as material for the disc, cast iron, steel, cupro-graphite, or aluminium could be employed. The other electrode (component) was of hard alloy (Russian types T15K6S and VK8). The working medium or fluid could be selected from various oils, emulsions, and air. The shaft extension of the existing grinding machine adapted for the purpose includes a brush-holder and current intake ring with textolite insulation.

In the search for optimum conditions of working, some 2,600 tests were made, with numerous variations in the basic factors. Various sets of curves show: (a) Relation between work done ( $P$  in terms of g./min.) and strength of current  $I$  at 20 v. potential, without capacity in circuit. Optimum speed appears to have been 10 m./sec. (peripheral), though somewhat higher (12-15 m./sec.) gave equally good results; with soft cutting tools it could be 25-30 m./sec. with current of 20 amp. Usually the best voltage was 20-25 v.; (b) Relation of  $P$  to current  $I$  and capacity  $C$  in mfd., with a fairly sharp (especially after 100 amp.) rise in  $P$  with increase of  $I$  up to 150 amp. and  $C$  up to 400 mfd.; (c) Relation of  $P$  to capacity  $C$  with speeds of 5 and 10 m./sec.  $P$  increased along a parabolic curve from 0.0-0.9 g. at 400 mfd. In these last two cases (b) and (c) the alloy was VK8, whilst in (a) it was T15K6S.; (d) quality of surface finish as represented by the Russian symbol  $N_{sk}$  (height of peaks in microns). The method appears to have given a finish corresponding to the 7th or 8th Class in Russian specification (GOST) 2789-56; with complete absence of micro-cracks. In all these tests a cast-iron disc was used, together with spent aviation oil

Mark MS as fluid medium. For the class of finish stated, optimum conditions were: current 3-5 amp., capacity 1-5 mfd. voltage 20 v., and disc speed 25-30 m./sec. In the tabulated results given later, the operations for different working surfaces of the tool were in each case: (A) grinding or sharpening and (B) finishing. The lower amperages and capacities relate always to the finishing operation, as also do the higher speeds. In the table some of the results are given with vibration (oscillation) and some without. Total time for grinding and finishing of the three edges was 3-5 min.

As it was thought that better indications of the efficiency of this electric spark method would be given by tests of the cutting qualities of the tools so treated, further curves and textual discussions relate to comparisons of results with tools treated by this (ES) method and the ordinary abrasive (Abr), used in machining various materials, including steel (18KhNVA) cast iron, etc. under varied conditions of working. These are given in Figs. 7, 8, 9 of the original. The results were uniformly in favour of the ES process. The first set shows the relation between surface finish ( $N_{sk}$ ) of hard alloy VK8 and capacity, with current strength of 20 and 70 amp. and potentials of 5 and 10. With low mfd. (below 50),  $N_{sk}$  was no more than 2½ microns, but rose very steeply to 4 at 400 mfd. and current of 70 amp. (at 5 v). The second set refers to the relation between the speed of cutting (m./min.) and stability  $T$  of the cutting tool for steel 30KhGSA of hardness  $H_B$  444, cutting regime being  $t \times s = 1.5 \times 0.47$  mm., using a tool of hard alloy T15K6C. This shows 5-10% better stability for ES, and large scale industrial experiments are said to have given still more impressive results. The third set shows the relation between surface finish of machined components and cutting speed.  $N_{sk}$  decrease from 2.5-1.3 microns is almost linear with increase in speed from 25-100 m./sec.

The electric spark method is also said to be superior in its effect on the quality of the tool, especially with respect to the brittleness of hard alloys. With the spark gap arrangement, there is said to be much less risk of damage to brittle hard alloys than is often experienced with abrasive grinding. The author concludes with some notes on the working medium to be used, working disc material, and method of use, together with some general instructions.



# LABORATORY METHODS

MECHANICAL · CHEMICAL · PHYSICAL · METALLOGRAPHIC  
INSTRUMENTS AND MATERIALS

FEBRUARY, 1951

Vol. XLIII, No. 256

## An Improved Null-Point Variable Aperture Photoelectric Absorptiometer

By J. W. Nicholas, M.R.C.S., L.R.C.P.

*Crittall Manufacturing Co. Ltd.*

*An absorptiometer is described of simple design which can be constructed in the average engineering factory. Permanence in calibration and an accuracy in density readings of 0.001 is to be expected.*

THE photoelectric absorptiometer described below was built to overcome as many as possible of the disadvantages with which users of commercially available instruments will be familiar. Since it was built, a new model (H 760) of the Spekker has been described (Isbell)<sup>1</sup> in which many of the disadvantages of the H 560 model have been overcome. Mention of the Spekker in this paper must normally be taken as referring to the H 560 model, which is at present in general use, or the H 602, which is the same instrument with a mercury-vapour lamp instead of a filament lamp.

The aim was to produce an instrument which would be permanent in calibration, convenient in use, and which would give accurate readings, in terms of true optical density, which could be used for spectrophotometric calculations as well as for purely absorptiometric work. Like the Spekker it was originally intended for medical use, but it has been found of great service in a metallurgical laboratory already equipped with a Spekker. It is described in this Journal because it is thought that metallurgists will have readier access to the means of constructing it.

Devices based on measuring the output of a single photocell (e.g., Evelyn<sup>2</sup>) were rejected as being too dependent on the characteristics of that photocell, which might well change without warning. Of the null-point designs, those using a potentiometer for measurement (e.g., Summerson,<sup>3</sup> Clayson and Scott<sup>4</sup>) were rejected for similar reasons. In spite of its advantages of linearity of calibration and constancy of aperture, a grey wedge (e.g., Humphrey and Harris<sup>5</sup>) was thought undesirable because it would involve different calibrations at different wavelengths. The calibrated variable aperture, as used by Messrs. Hilger<sup>6</sup> in their Spekker, was thought most suitable. Until recently, the latter instrument had a sliding shutter actuated by an eccentric circular brass cam, and was liable to wear, sticking on the return movement, and backlash. The instrument here described entirely avoids these disadvantages by using an eccentric circular shutter directly connected to the measuring drum.

The design is such that high precision in manufacture is not required and its construction is well within the capacity of the ordinary engineering tool room or machine

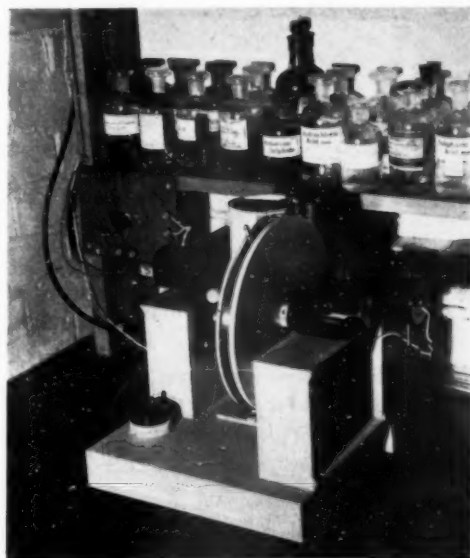


Fig. 1.—Photograph of instrument.

shop. The general arrangement of the instrument can be seen from the photograph (Fig. 1) and the front elevation and horizontal section (Fig. 2).

### Body of Instrument and Lamphouse

The body of the instrument is built up from steel channel, reinforced where necessary by welded webs and machined to the required size. The lamphouse is made of 3½ in. diameter steel tubing, bored to take a steel ring which acts as a rotating shutter. The ventilation is good and it gets much less hot than the double-walled lamphouse of the Spekker. The shutter, resting as it does on a machined shoulder, is not liable to wear.

### Optical System

The light source is a mercury-vapour projection lamp of 125 watt by Siemens (type MB/D).<sup>\*</sup> It is placed

<sup>\*</sup> References to the literature will be found at the end of the article.

<sup>\*</sup> A.C. and D.C. models are both satisfactory.

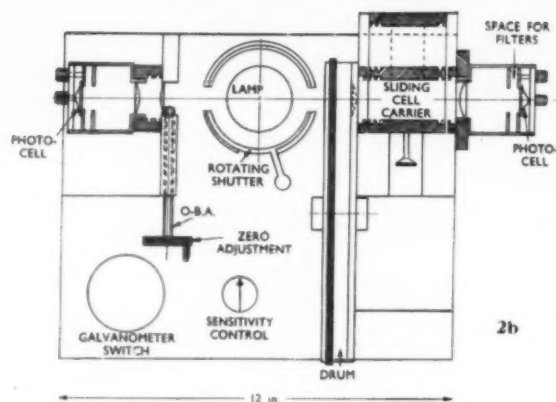
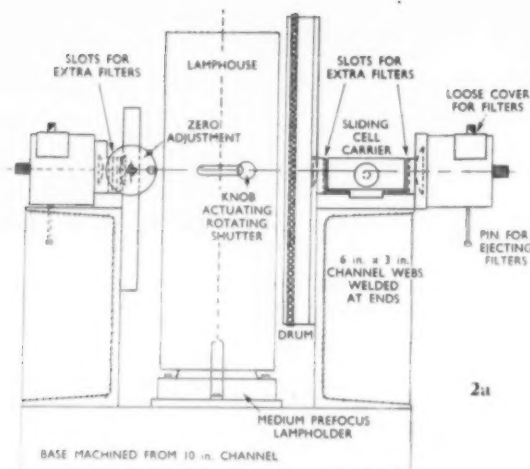


Fig. 2.—General lay-out: (a) Front elevation; (b) horizontal section through optic axis.

between two lenses\* of 25 mm. diameter and 75 mm. focus and at the focus of both. The aperture of both these lenses is adjustable, the right-hand aperture being calibrated. The collimated beams are brought to focus on the photocells by lenses of 50 mm. focus, that on the right-hand side being 31 mm. diameter to allow for the spread of the right-hand collimated beam in its longer path. The illuminated area of each photocell, therefore, remains constant, and variations due to lack of uniformity in the photocells are not to be expected. As the lenses will probably not be perfectly centred, alignment by optical rather than engineering methods will be necessary. The drum may be securely fixed in position, but over-size screw holes should be made in other components to allow for alignment during assembly.

#### Measuring Drum†

This has been made considerably larger than on the Spekker, and is 9.25 in. diameter. It consists of a phosphor-bronze disc rotating on an angular-contact ball-bearing between two fixed steel discs. There is a clearance between the left-hand and middle discs, but the periphery of the middle disc bears on the right-hand disc, and the contact-pressure here is adjustable by means of a nut and resilient washer at the centre of the drum. A semi-circular slot is milled in the bronze disc, and overlapping this are two brass rings with knife edges, the inner one being placed eccentrically so as to leave a tapering semi-annular space between them. The right-hand disc bears two straight knife-edges, placed horizontally, and a simple convex lens of 25 mm. diameter and 75 mm. focus. Both rings and knife-edges are chamfered to an included angle of 60° and should be chemically blackened so as to secure a non-reflecting, non-flaking surface.

For ease of calibration, the scale is removable and takes the form of a strip of stainless steel, 0.010 in. thick, wrapped around the periphery and held in tension by a screw through blocks at its ends. The aperture is arranged to open from 10 mm.  $\times$  1.25 mm. to 10 mm.  $\times$  20 mm., thus giving a density range of 0.1–2. The useful length of the scale is 35 cm. and the minimum

space occupied by a density difference of 0.100 is 16 mm. The density scale is calibrated every 0.005, and densities can be read with ease to 0.001.

#### Compensating Side

The left-hand (compensating) side is made as far as possible the optical equivalent of the right-hand side. The zero adjustment is a screw-operated aperture in the plane of the collimating lens. A second lens focuses the light source on the photocell, and between the two lenses is a space for filters. The end of the screw itself constitutes the shutter, so as to simplify construction and avoid backlash.\* The aperture is 4 mm. wide and adjustable in length from 0–20 mm. The screw is of 1 mm. pitch (0 B.A.) and is operated by a knurled hand-wheel. To avoid the necessity of closing this aperture when setting the sensitivity, a hinged shutter is also provided by which the left-hand aperture can be completely occluded without upsetting its adjustment. No water cell is used on the compensating side, as it only absorbs radiation above 1.4  $\mu$  which is not registered by the photocell and which, contrary to a widely held view, does not damage the latter.† No harm has been found to result from its elimination, either from the present instrument or from the commercial Spekker.

#### Photocells and Electrical Arrangements

Selenium rectifier photocells, 25 mm. in diameter, supplied by Evans Electro selenium, Ltd. are used in pairs, matched by the makers for output at 405, 546 and 577  $m\mu$ . They are connected in parallel, in opposition, across a sensitive galvanometer, as circuits of this nature are more stable than the series-opposing type (Lange,‡ Brice§). A potentiometer serves as both sensitivity control and as critical damping resistance for the galvanometer. A tumbler switch is connected in parallel with the potentiometer to short-circuit the galvanometer when not in use. The parallel connection here not only protects the galvanometer more effectively, but also avoids difficulties due to variable contact resistance which may arise even with a mercury switch when it is in series. The manipulation of the galvanometer switch for each reading is an unnecessary complication and no harm

\* The optical quality of these lenses does not require to be very high. Lenses of spectacle quality supplied by Messrs. Groulands, of Croydon, have been found quite suitable.

† See Fig. 2.

‡ Although this is the final design, the model illustrated in the photograph has a rather different (and less simple) adjustment.

§ Evans Electro selenium, Ltd.—Personal Communication.

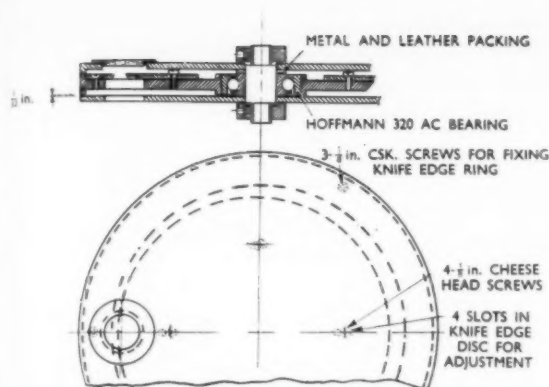


Fig. 3.—Detail of drum: Horizontal section through optic axis, and side elevation showing position of lens and knife-edge rings.

will be done if this switch remains open throughout the period during which the instrument is being used.

In the present instrument, the photocell circuit is fully insulated, and the base of the instrument is earthed. This avoids the possibility of galvanometer deflections on touching the instrument with which many users of the Spekker will be familiar. There is also no possibility of danger to the galvanometer in the event of a short-circuit developing between the lamp supply and the base.

A Cambridge Spot Galvanometer, as used with the Spekker, can be used, but it will be found more useful to have a more sensitive galvanometer which will allow the measurement of high densities and the use of dense filters and weak lines—e.g., Tinsley type VS 6/45, with a variable sensitivity of up to 1,950 mm./ $\mu$ A.

#### Filter Carriers and Filters

Stross,<sup>9</sup> using the Spekker, has drawn attention to the fact that, with some filters, readings vary significantly if the position of the filter is altered. This is because, when it is placed near either lens, or in the collimated beam between the lenses, different areas are illuminated at different apertures. Any irregularities in the density of the filter will therefore cause corresponding irregularities in the calibration of the instrument. As a tolerance of 10%\* is allowed in the thickness (and therefore the density) of Wratten filters,<sup>†</sup> it will be seen that, either they must be carefully selected, or they must be placed in an image-plane where the illuminated area will be constant. A filter carrier has, therefore, been placed immediately in front of each photocell. In this situation it is, of course, necessary that it should be adequately light-trapped and fitted with a light-excluding cover. It is realised, however, that it may sometimes be desirable to filter the light before it passes through the unknown solution, especially if the latter is photolabile or strongly fluorescent. A filter-carrier is therefore also provided between the drum-lens and the solution-cell carrier.

Imaging the light source on a gelatine filter may possibly be detrimental to the filter, but Kodak, Ltd.,<sup>‡</sup> state that their filters should have a working life of at least 100 hours when used in this position on this

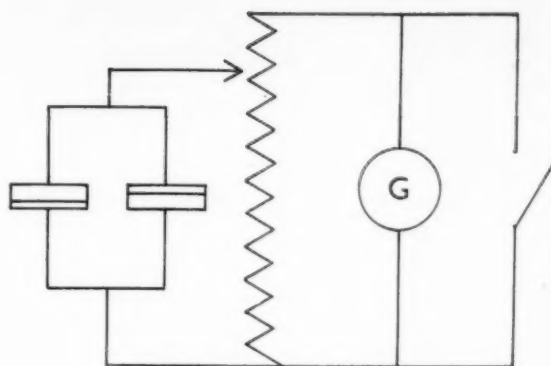


Fig. 4.—Wiring diagram.

instrument. As they are only illuminated while actually taking readings, this should be adequate, but it would be possible to extend their life by using them in the alternative aperture-plane for routine work where the highest accuracy is not required. (The area illuminated would actually not be very much greater, but would be in a different part of the filter).

When a filter is placed immediately in front of the photocell, care must be taken that fluorescence does not introduce inaccuracies. The filter combinations used take this into consideration by the arrangement of their components. These combinations are the series described by Nicholas and Pollak,<sup>10</sup> which give sharp isolation of the lines at 365, 405, 436, 546 and 577  $m\mu$ , and reasonably narrow wavebands centred around 492, 612 and 691  $m\mu$ , with a band in the infra-red above 735  $m\mu$ . They are cemented as compound filters between glass plates 1½ in. square.

#### Cell Carrier

A heavy brass carrier slides on machined ways and provides spaces for two cells of optical depth up to 4 cm. There are grooves in both compartments to take filters, so that these may be used in calibration and to extend the range of the instrument (High<sup>11</sup>). These grooves also serve to carry the standard 1½ in. square Tintometer capillary cell. The provision of only two compartments avoids the use of a ball-catch for locating; movement between the end-stops can therefore be perfectly smooth.

#### Calibration

Unlike commercial absorptiometers, which are calibrated in units approximating to optical density, the scale on this instrument is calibrated in true density. A standard of density is therefore required and for this a Chance neutral filter of density about 0.5 is calibrated by the National Physical Laboratory for the green line (546  $m\mu$ ).<sup>\*</sup> A filter of density about 0.07 is also required, and this is referred to as the secondary standard; it is not necessary to know the true density of this filter beforehand. Two pieces of clear glass bound together, but not actually in contact, will give the required value. A temporary arbitrary scale (e.g., a strip of millimetre graph paper glued to a steel strip) is first attached to the drum. Using the 546  $m\mu$  line, the secondary standard is placed in one compartment of the cell-carrier and the other left empty. The density of the secondary standard

\* This appears to be a maximum figure and the author has not found a filter of the type used to vary across its width by so large an amount. Nevertheless, filters do sometimes show marked density gradients.

† Kodak, Ltd.—Personal Communication.

\* This is chosen as the only strong single line.

is read repeatedly: the drum is not reset to zero after each reading, but the null-reading on the galvanometer is restored by use of the zero adjustment on the compensating side. (If it is found necessary to go beyond the range of this adjustment, the intensity of light on the right-hand side is reduced by a neutral filter). The primary standard is then read on the instrument, and the true value of the secondary standard found by interpolation. To avoid cumulative error, it is necessary to calculate the density of the secondary standard to five places of decimals. Readings are then plotted against density: further readings of the secondary standard are made, starting from different drum readings on a straight line part of the curve, and from these the more sharply curved parts of the graph are filled in. The arbitrary scale is then removed from the drum, clamped to a flat surface alongside another stainless steel strip and, using a square and scriber, the final scale is drawn.

The process of calibration is not lengthy, apart from actually cutting the scale, and even including this it is much quicker to recalibrate in densities after any alteration is made to the instrument (e.g., a new lamp) than to prepare fresh calibration curves for a number of estimations. In view of the changed position of the filter, it is not necessary to recalibrate after replacing a filter.

The scale is arranged in the direction opposite to that of the Spekker—i.e., with zero at minimum drum aperture: this will be found more generally convenient.

### Performance

As an example of the reproducibility of readings, the accuracy of calibration attainable, and a demonstration of the independence of the reading of differences in the filters, Table I is given. The "unknown" was a neutral filter calibrated by the N.P.L. at 546  $m\mu$ , but was not

the same filter as that used for calibrating the instrument. Different monochromatic filters (546  $m\mu$ ) were used on the right-hand side for each reading, these being placed immediately in front of the photocell. No special care was taken to ensure that the filters were clean, and two of them (NL and NR) were defectively cemented, having air-spaces which, in the case of the former, covered nearly the whole area of the filter. For comparison a number of these filters were also read on the H 602 Spekker, where the filter is placed to the left of the drum. The Spekker was set air/air 0.6.

TABLE I.—READINGS ON NEUTRAL FILTER OF DENSITY 0.488 (N.P.L. Calibration)

Designation of Filter	Density (New Absorptometer)	Drum Difference (Spekker)
AR	0.486	—
AL	0.486	—
SB	0.487	0.509
SL	0.487	0.480
AAR	0.486	—
AAL	0.488	—
NR*	0.487	0.471
NL*	0.487	0.459
Sep. H†	0.487	0.471
Sep. L†	0.487	—

\* Imperfect filter.

† Separate elements of combination not cemented together.

It will be observed that the mean reading on the new instrument is 0.4868 and the standard deviation of all readings 0.000067.

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## Improved Automatic Loading Balance

SINCE they produced the first fully automatic loading balance in Great Britain, in 1948, Stanton Instruments, Ltd., have incorporated many new features in their aperiodic balances.

These include the following:—

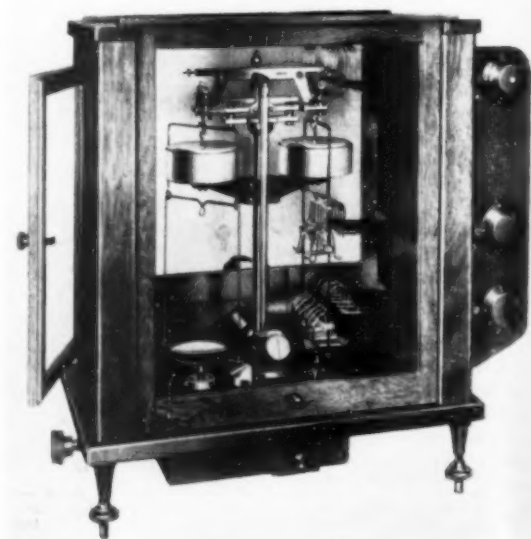
- (1) A mercury switch operating the light as the beam is released is now fitted, but its use is optional as it can readily be disconnected for those who prefer permanent illumination.
- (2) The arrestment mechanism is now fitted with agate bearing points, to give a smoother set-off, and obviate sticking due to corroded points.
- (3) Green filters are incorporated in all projection reading balances in order to reduce further the transfer of heat to vital parts of the instrument, to give a clearer image on the screen, and to reduce eye-strain.

Although these features are included in the new re-designed Models B.A.5., B.A.6., and B.A.7., the most striking improvement will be found in the loading attachment. The weight loading device will, as hitherto, be operated by a series of cams and levers, but these have been redesigned so as to give perfectly smooth application and fingertip control for even the heaviest weights. The new device is housed in an easily detachable case to facilitate access to the various parts.

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of operation is imperative, but for which, in many cases, only semi-skilled operators can be found.

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# Some Factors Affecting Microhardness Values

B. B. Hundy,\* B.Sc., Ph.D.

*In all methods of hardness testing, the adoption of the correct technique is essential if reliable results are to be obtained. In no case is this more true than in that of microhardness testing and in this article the author discusses possible sources of error.*

IN recent years, the microhardness tester has become established as an important research tool, and it is very desirable to know what factors affect the hardness values obtained by this method.

A certain amount of research on the subject has already been carried out by other investigators, notably by Bergsman<sup>1</sup> and Bischof and Wenderott<sup>2</sup>. The object of this article is to correlate this work with the author's own experimental results.

A study of the previous work reveals that the factors affecting microhardness values can be classified under four headings:—

1. Accuracy of measurement of impressions.
2. Effects inherent in the specimen under test.
3. Effects in operation during indentation.
4. External effects.

## Experimental Conditions

Two instruments, the Bergsman Microhardness Tester and the Cooke, Troughton and Simms Microhardness Tester were available for use. These testers are both of the "balanced beam" type and, although they have been fully described in papers by the designers,<sup>3,4</sup> a brief description of the principles on which they operate will be given.

The microhardness tester is mounted on the specimen stage of a metallurgical microscope, with a vertical optical axis and an objective directed upwards. The instrument consists of a light beam pivoted at the centre, so that it is free to move in a vertical direction, and supported at one end by a pair of electrical contacts. The sample to be tested is fastened into a holder at one end of the beam, and the weight of this and the beam is balanced out by means of counter weights on the other end. Thus, this weight will not affect the indentation load, which is applied directly, by placing the requisite weight (up to 200g.) on the beam above the sample. After location of the area for testing, the objective is replaced by a standard diamond pyramid indenter, which is moved upwards into contact with the specimen by means of the focusing screws. When the electrical contacts are broken, the full load is supported by the indenter and an impression is made. The indentation is measured by the normal methods.

In the present series of experiments, the testers were mounted on a Vickers Projection Microscope. Two indenters were available, one a standard Vickers pyramid indenter mounted in an objective holder, and the other a pyramid indenter mounted in the upper lens of an

objective. Comparative tests made with both instruments and with both indentors gave identical results.

The materials used in this investigation were work-hardened O.F.H.C. Copper (80% R.A. by rolling); annealed O.F.H.C. Copper; and cold-worked mild steel (9% R.A. by rolling).

## Factors Affecting Microhardness Values

### 1. ACCURACY OF MEASUREMENT.

For reliable work, it is essential that all impressions should be measured as accurately as possible. Some investigators suggest using an eyepiece screw-micro-meter but, in the opinion of the author, more accurate results are obtained if the following method is adopted.

The image of the indentations is projected at a magnification of  $1,000\times$  on to a millimetre grid screen and the diagonal lengths are read directly from this. An engraved standard scale must be used to standardise the magnification, and all measurements should be made using a lens with the highest possible resolving power. To relieve eyestrain, it is suggested that the best results are obtained with a mercury vapour lamp and small diaphragm apertures.

Under these conditions, measurements can be made to 0.5 microns; this gives an error in hardness of 0.6 V.P.N. with a material whose hardness is 50 (error of 20 with a hardness of 500).

On the Vickers Projection Microscope, fine focusing is effected by movement of the objective lens. It was found that if the objective is moved through a distance of  $\frac{1}{4}$  in. (the maximum traverse), the magnification obtained varies from  $1,000\times$  to  $985\times$ . Care should be taken to minimise this error, as it can lead to an apparent increase in hardness of up to 3%.

### 2. EFFECTS INHERENT IN THE SPECIMEN UNDER TEST

(a) *Surface preparation.* It is essential, for microhardness testing, that the metal under test should be given a metallographic polish. In the past, anomalous hardness results have often been attributed to a hard surface layer caused by this polishing.

Bischof and Wenderott<sup>2</sup> have already shown the effects of different methods of surface preparation on the hardness of soft iron, and it seems from their work that a poor polish may give rise to excessively high hardness values at low loads.

Further tests were carried out by the author on annealed copper and mild steel. The copper was polished electrolytically and hardness tests were made using loads of 200, 100 and 25 grams. The specimen was then repolished by hand using "Brasso" and "Silvo" on a Selvyt cloth. On retesting, the hardness was found to be higher than before, with no fall of hardness at the lower loads (Fig. 1). This seems to indicate the presence of a work-hardened surface layer on the copper.

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<sup>1</sup> Bergsman, E. B., Factors affecting microhardness testing, *Jernkontorets Arbet*, 1945, **129**, 577.

<sup>2</sup> Bischof, W., and Wenderott, B., Applications and limitations of microhardness testing, *Archiv für das Eisenhüttenwesen*, 1942, **15**, (11), 497.

<sup>3</sup> Bergsman, E. B., A simple accurate microhardness testing device, *Metal Progress*, 1948, **54**, 165.

<sup>4</sup> Taylor, E. W., Microhardness testing of metals, *Journal of the Institute of Metals*, 1948, **74**, 493.

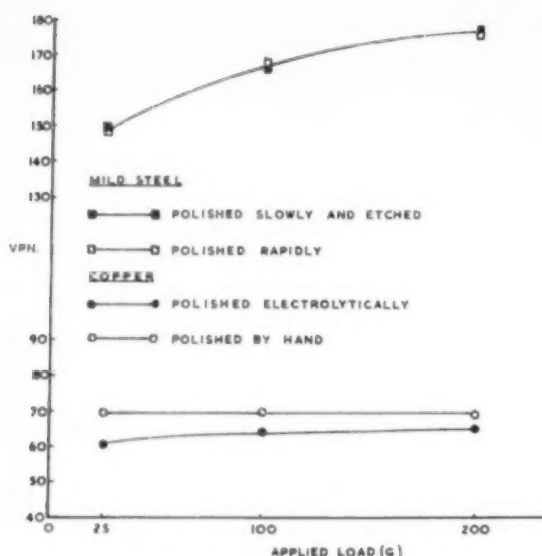


Fig. 1.—Effect of surface preparation.

The mild steel sample was carefully polished with B.C.I.R.A. polishing cream on a slowly moving wheel, and the metal surface was etched before testing. It will be seen (Fig. 1) that there is a substantial drop in hardness with lower applied loads, indicating that there is no work-hardened layer. The sample was then repolished on a fast wheel with chromium oxide; on retesting there were no detectable differences in hardness. Thus, it seems that it is only with soft metals that the hardness values are affected by a worked surface layer due to polishing.

(b) *Planeness of surface.* Hengemühle<sup>5</sup> has demonstrated that the hardness measurements will be in error if the axis of the indenter is not exactly perpendicular to the surface of the specimen under test. Unreliable results will also be obtained if the surface of the specimen is at all wavy. This error may be indicated by irregularly shaped impressions, and care should be taken to minimise its effect by levelling all specimens before testing.

(c) *Influence of grain boundaries.* By taking care, it was found possible to make hardness measurements both in the centre of grains and at the junction of grains. Tests were made with a 25 g.-load on the etched surface of copper and of mild steel. It can be seen from the results (Table I) that the hardness at the grain boundaries is rather higher than the hardness in the centre of the grain.

TABLE I

Material	Average hardness (centre of grain)	Average hardness (grain boundaries)
Copper .. .. .	57.1	61.3
Mild Steel .. .. .	147.8	158.5

This difference in hardness may be due to the abnormal arrangement of the atoms in the region of the grain boundaries or to impurities or segregation at the boundaries.

<sup>5</sup> Hengemühle, W., Scatter in hardness tests on Steel, *Stahl und Eisen*, 1942, **62**, 321.

From the results obtained, one would expect the average hardness value of a sample to vary with the grain size, a small grain size giving a high hardness. It is also highly probable that the variations in hardness from one impression to another in a homogeneous sample are a reflection of this effect.

(d) *Effect of neighbouring grains.* Bischof and Wenderott<sup>2</sup> have shown that grains of one phase can affect the hardness of grains of a different phase, and that the chances of obtaining a correct measurement depend on the applied load and the grain size. If the hardness of a single phase in a duplex material is to be determined, the applied load should be chosen so as to give the highest number of correct hardness values for a given grain size.

Boas and Hargreaves<sup>6</sup> have also shown that the hardness varies across a single grain after working, and that the hardness variation is affected by the hardness of the neighbouring grains.

(e) *Orientation of the grains.* Bergsman<sup>1</sup> has demonstrated that the shape of the indentations is dependent upon the orientation of the grain in which the test is made. Normally this effect is beyond control and must be ignored.

### 3. EFFECTS IN OPERATION DURING INDENTATION

(a) *The diamond indenter.* Campbell, Henderson and Donleavy<sup>7</sup> have shown that, if accurate hardness numbers are to be obtained at low values of the applied load (less than 100 grams), then the tip of the diamond indenter must have a perfect point and not a chisel edge as is common with many commercially produced macro-indentors.

Examination of the indentors used in these experiments revealed no sign of this chisel-type tip.

(b) *Frictional drag in the bearings.* It is possible that, at low loads, the applied force might be affected by frictional forces acting in the bearings. To test this, the beam was balanced as usual and successively smaller weights were placed on the end of the beam opposite the electrical contacts. It was found that as

<sup>6</sup> Boas, W., and Hargreaves, M. E., On the inhomogeneity of plastic deformation in the crystals of an aggregate, *Proceedings of the Royal Society*, 1948, **193** (A), 89.  
<sup>7</sup> Campbell, R. F., Henderson, Q., and Donleavy, M. R., A new design of micro-hardness tester and some factors affecting the diamond pyramid hardness number at light loads, *Transactions of the American Society of Metals*, 1948, **40**, 954.

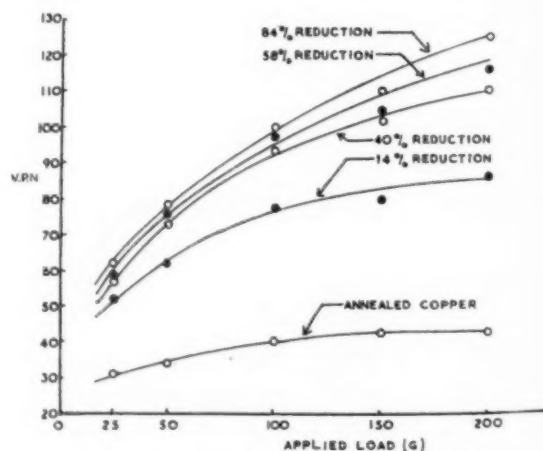


Fig. 2.—Effect of applied load (Rostoker).

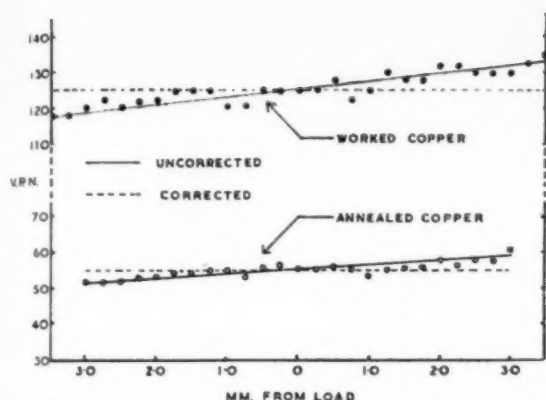


Fig. 3.—Effect of the position of the load with respect to the indenter.

little as 50 mg. would appreciably displace the beam. It was assumed, therefore, that this effect was negligible and in most cases could be ignored.

(c) *Applied load.* Rostoker<sup>8</sup> has recently published a comprehensive paper on the effect of applied load on micro-indentations, using the Bergsman microhardness tester. The results of Rostoker's investigations on copper are reproduced here (Fig. 2). This work appears to be at variance with a number of other investigators but an exactly similar effect has been observed by the present author (Fig. 1).

It will be seen that the general effect is for the hardness to increase with increasing load, the effect being particularly pronounced with highly worked materials.

Rostoker tentatively ascribes this effect to elastic recovery in the indentation but, in our present state of knowledge, it is difficult to say whether this explanation is correct.

If comparative measurements are to be made, the load should be kept constant and, wherever possible, it should be standardised at 200 g. This load was used for the majority of tests in this investigation.

(d) *Position of the applied load.* To obtain the full effect of the applied load, it must be situated directly

above the point of contact of the indenter. This was demonstrated by making impressions at different points in line with the beam of the tester while keeping the load in one position. If the hardness is plotted against distance from the centre of gravity of the weight (Fig. 3), it can be seen that it progressively varies from one end of the sample to the other. By taking moments about the pivot it is possible to calculate the actual load applied at each point. If these corrected loads are used to recalculate the hardness, there is no appreciable variation in hardness along the length of the sample.

It is suggested that sufficient accuracy will be obtained if the load is centred within 1 mm. of the indenter axis by means of an independent indicating pointer.

(e) *Speed of loading.* Very little systematic work has been carried out on this effect, but Bischof and Wenderott<sup>2</sup> showed that the penetration is not smooth if the rate of loading is too low, and Bergsman<sup>1</sup> states that the loading speed should be kept low, so as to minimise any kinetic effect. Thus, it seems as though there will be an optimum range of penetration speeds giving the most accurate hardness value.

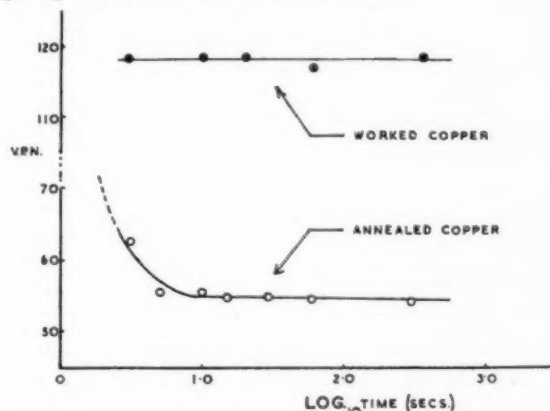


Fig. 5.—Effect of time of contact between indenter and specimen.

Tests were carried out to determine this and it was found that, provided the load is applied by means of the fine focusing screw on the Vickers Projection Microscope, the speed of loading has little effect (Fig. 4). At very low indentation rates there is a certain scatter of results and the average hardness value is slightly lower than with higher speeds. This may be due to external factors affecting the impression during the longer contact time, or to the uneven penetration shown by Bischof and Wenderott.

It seems that a loading speed of 10–15 microns per second is most convenient.

(f) *Time of contact between indenter and specimen.* Bergsman<sup>1</sup> states that the duration of indentation should be long enough for static conditions to prevail, and he also suggests that this time varies with the material.

Investigation showed (Fig. 5) that the hardness of a highly worked material is not affected by the duration of the test, but that with a material of low yield strength (annealed copper) the hardness is definitely lowered. It is thought that this fall in hardness with time of contact is due to creep of the metal round the indenter during testing. It seems that 30 seconds is sufficient time for

<sup>8</sup> Rostoker, W., The effect of applied load in micro-indentation tests, *Journal of the Institute of Metals*, 1950, **77**, (11), 175.

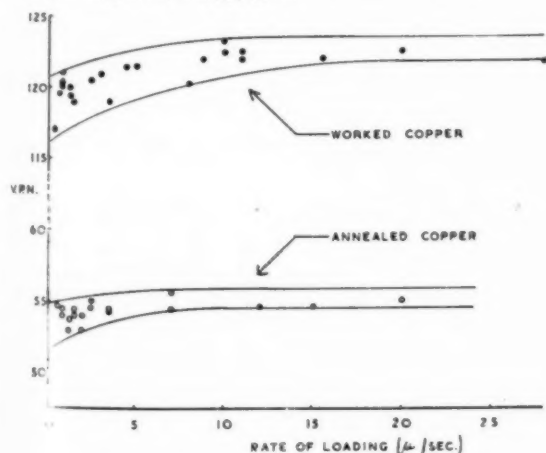


Fig. 4.—Effect of rate of indentation.

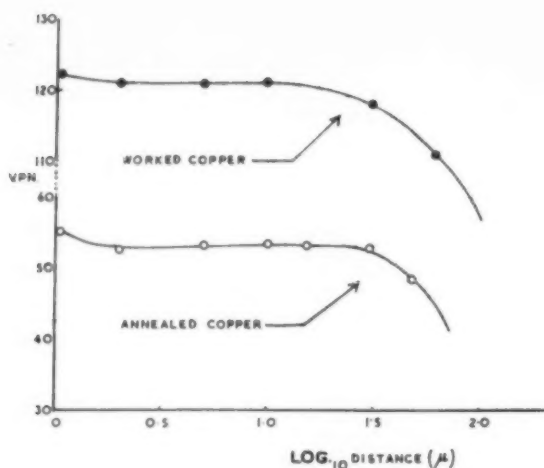


Fig. 6.—Effect of advancing indenter after contacting specimen.

nearly static conditions to be reached, and it is suggested that the indentation time should be fixed at this figure for soft metals. For hard metals the indentation time can be reduced to 15 seconds with safety.

(g) *Height to which indenter is raised after contact with specimen.* When a test is made, it is advisable to raise the indenter through several microns after making contact with the sample. If this procedure is not followed, creep of the metal round the indenter may occur so that some of the applied load may be taken by the electrical contacts on one end of the beam, leading to erroneous hardness values.

This effect is shown in Fig. 6, where it can also be seen that, if the indenter is raised through more than 30 microns, the impressions are distorted and enlarged, with a corresponding fall in hardness. The distance moved through should be standardised at 5 or 10 microns.

#### 4. EXTERNAL EFFECTS

(a) *External vibrations.* If the instrument is subjected to vibrations during testing, the impression may become enlarged, with a corresponding decrease in the measured hardness. This effect is illustrated in Table II, where it can be seen that this error is reduced when the microscope stands on a thick Sorbo rubber pad.

TABLE II

Conditions	Hardness	Average V.P.N.
Normal conditions . . . . .	123.1	123.1
Heavy weight dropped on floor near microscope . . . . .	61, 103, 110	91.1
As above but microscope cushioned with a rubber pad . . . . .	118, 120.5, 120.5	119.7

(b) *Mechanical faults in the microscope.* When this model of the Vickers Projection Microscope has been in use for some time, adjustment of the fine focusing screw may cause a slight lateral movement of the objective. If the indenter is in place of the objective and lateral movement occurs on withdrawal during testing, there is a tendency for overlarge indentations to be formed, giving rise to very low hardness values. This error can usually be checked by careful examination of the

impression, which appears to have been made with a chisel edge instead of one with a perfect point. *e.g.* Hardness measured with loose gears, 60.7 V.P.N. Hardness measured after overhaul, 66.8 V.P.N.

It is advisable to have the microscope overhauled at regular intervals to prevent this effect.

#### Conclusions

It is recommended that, whenever possible, the specimen under test should be electrolytically polished; if this is not possible, a very careful metallographic polishing technique should be employed. In the latter case, a light etch might be advisable but this should not be carried out if the sample becomes too dark for accurate measurement of the impressions. A magnification of at least 1,000  $\times$  is essential to obtain the greatest accuracy in measurement and, where possible, a number of indentations should be made so that an average hardness value can be obtained.

During testing the following factors must be standardised:—

1. The applied load and its position in relation to the indenter.
2. The speed of loading.
3. The duration of indentation.
4. The distance through which the indenter is moved after contact with the sample.

Provided that all the factors are kept standardised, and that external vibrations, etc., are excluded, reproducible results are obtainable with the balanced beam microhardness tester.

Examples of reproducibility are given in Table III.

TABLE III

Metal	Single Impressions			Average of 5 values		
	Av. V.P.N.	Min. V.P.N.	Max. V.P.N.	Av. V.P.N.	Min. V.P.N.	Max. V.P.N.
Annealed copper . . . .	55	52	57.5	55	54.5	55.5
Work-hardened copper . . . .	120	116	125	120	118.5	121
Mild Steel . . . . .	175	169	180	175	173	176.5

#### Acknowledgments

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#### Scholarships Abroad 1951-52

THE British Council has published a handbook which gives details of some 70 scholarships offered by 15 foreign governments and universities to British students for the academic year, 1951-52. The scholarships in most cases correspond to those offered by the British Council from these countries. The British Council is assisting in publicising the offers and, in most cases, in the administration of the selection boards.

Although mainly for post-graduate study, some scholarships are open to those not yet graduated and to those with non-academic professional qualifications. They provide free tuition and maintenance, and the majority are tenable for the complete academic year, with a few for shorter periods.



## B.T.H. Research Activities in 1950

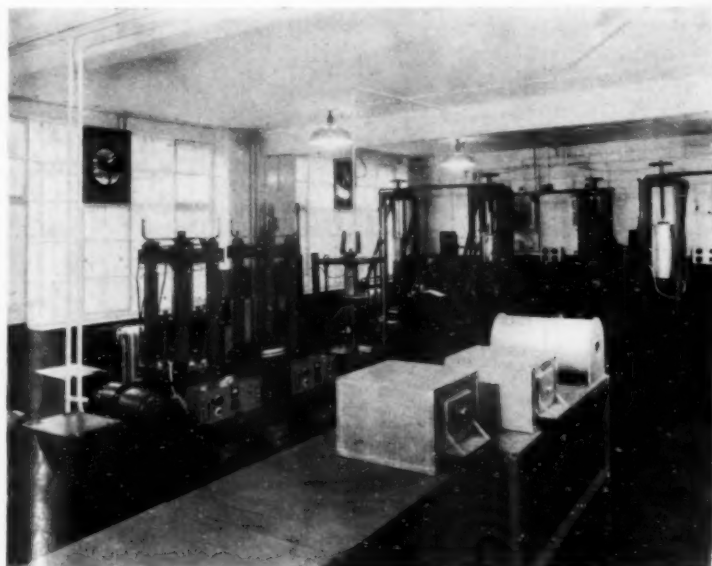
THE work of the research department of a large engineering concern usually comprises guidance to design engineers and workshops, *ad hoc* investigations, and a certain amount of long-term research work. In the B.T.H. Research Laboratory, the field can be divided broadly into Materials and Devices and Processes, and in these notes an indication of the Laboratory's activities is given by references to some investigations and developments in the metallurgical field.

**Magnetic Sheet Steel.**—Work on the properties of magnetic sheet steel, involving a study of electrical and magnetic properties and their dependence on chemical composition, crystal size and crystal orientation, has been continued. Both optical and X-ray diffraction methods of determining crystal orientation in sheet steel have been developed further, and are now firmly established as useful tools for the examination of sheet samples. In addition, the method of carbon determination developed a year or two ago has been used effectively for examining both commercial samples and samples of sheet prepared in the laboratory. Considerable improvement in magnetic properties can be achieved by suitable heat treatment and new equipment has been set up for dealing with laboratory samples. It has been found possible to reduce the carbon content of silicon iron sheet from 0.03%–0.005% in a short time, and by suitable annealing treatment to develop crystals of large size (up to several inches long) with corresponding improvement in magnetic properties. Other apparatus built during the year has included a miniature Lloyd-Fisher test set for the determination of watts loss in 25 cm.  $\times$  3 cm. samples, these samples being the size which can be produced with the Laboratory rolling, processing and annealing equipment. There has also been built an induction furnace designed to operate

under vacuum conditions, or with controlled atmospheres of high or low pressure, and suitable for the melting of small metal ingots.

**Induction Furnace.**—Power for the induction furnace is obtained from a B.T.H. high-frequency generator, rated at 10 kW and approximately 400,000 cycles/sec. The vacuum system itself consists of a vacuum chamber (a silver tube, 4 in. in diameter and 20 in. long) connected to an oil-diffusion pump, rated at 400 litres/sec., with baffle valve, and associated equipment. A Pirani gauge with a platinum filament is used to measure the fluctuating pressures in the chamber, the range covered by the instrument being from 2 mm. to 1 micron. The apparatus has been designed for the heating of small charges of material in atmospheres of widely differing compositions and pressures. In this way the apparatus has been made as flexible as possible so that it will be useful in various investigations.

**Physical Analysis.**—The spectrographic and X-ray diffraction analysis service continues to be called upon with increasing frequency. While numerous analyses have involved X-ray diffraction for the identification of the crystalline phases present, the most important and interesting applications of this technique recently have been in the fields of crystal orientation and texture (i.e.



Thermostatically controlled room with creep and fatigue testing machines.



Vacuum furnace with H.F. oscillator.

the distribution of grain orientation in a poly-crystalline material). Work with the Geiger-counter and goniometer has been continued, and this method of determining crystal orientations has been further developed, being applied to silicon-iron sheet, and also to samples of germanium and tungsten, containing crystals large enough to be studied individually. A new X-ray diffraction apparatus has been developed for texture studies, known as a "texture mapping camera."

**Mechanical Testing.**—Increasing attention is being paid to the mechanical properties of metals at high temperature, and a large thermostatically-controlled room has been set up to house all the creep and fatigue testing machines. Many of the steels specially developed for creep resistance are of the precipitation hardening type and, by means of creep tests carried out at different stresses, work on the theoretical relationship between creep strain and stress for such materials is being carried out.

Blading and bolting materials for gas and steam turbines are tested at stress and temperature conditions under which the components will operate. The relaxation property of molybdenum vanadium steel has been determined by simulating the daily stress cycle resulting from the cooling and reheating of the turbine.

The temperature of operation of steam turbines is now such that resistance to high temperature steam corrosion is as important as good creep resistance, and it is desirable that the scale formed should be adherent and help to protect the metal from further oxidation. Small

cylindrical specimens are subjected to heating and cooling in an atmosphere of nitrogen, and while at high temperature, a steady stream of superheated steam passes over the metallic surfaces. At the conclusion of the test, measurement is made of the extent of corrosion and the degree of adherence of the oxide scale.

**Welding.**—Examination of test welds has resulted in the development of a satisfactory procedure for the welding of gas turbine rotor forgings. In this connection, work has proceeded on the metallography of austenitic steel weld metals used for this purpose. Attention has been mainly directed to the formation of sigma phase and hot cracking; an etching technique for positive identification of sigma phase has been developed.

### Bromide Paper Developer

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